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ASTRONOMY

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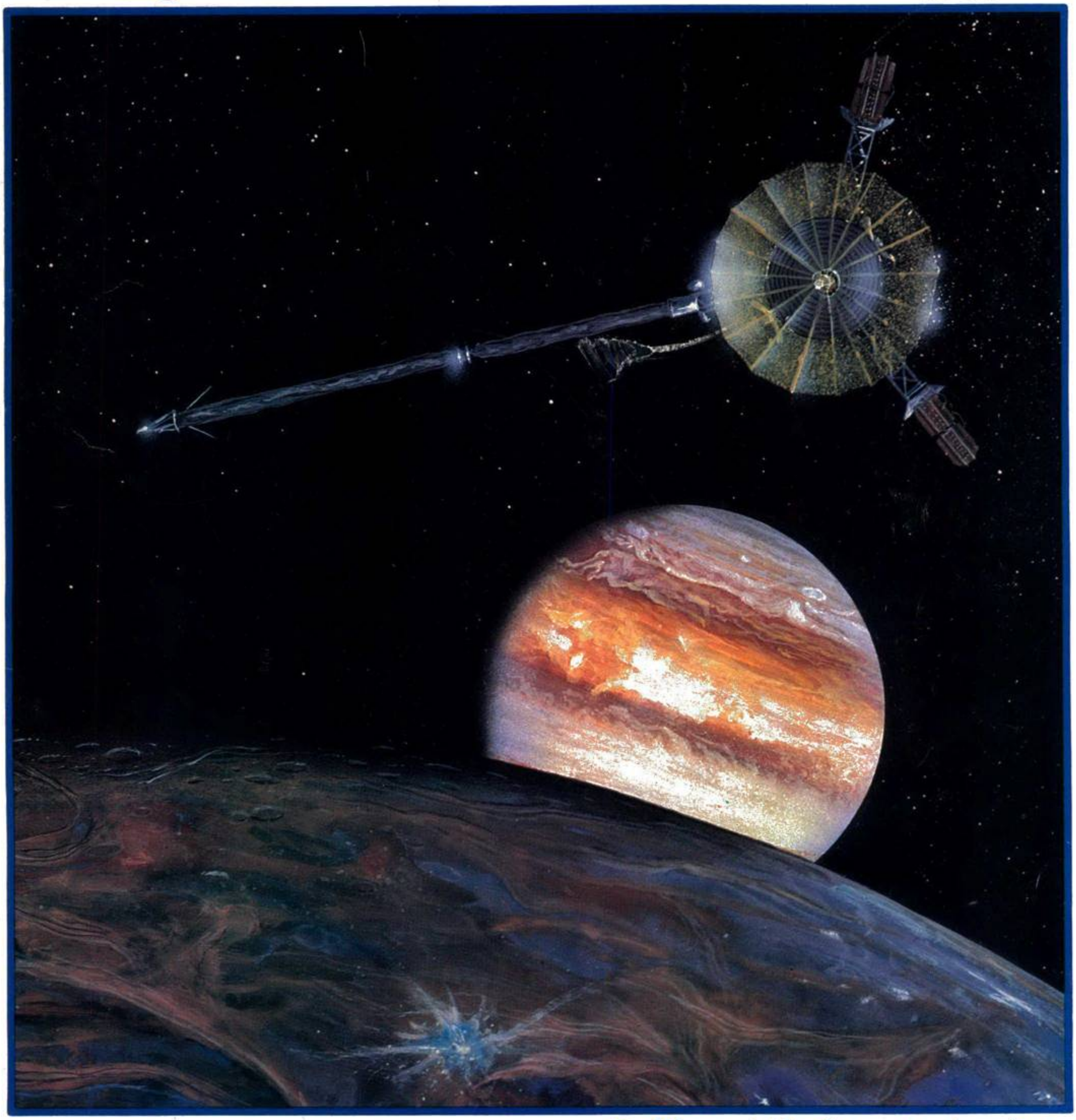
A Visit to the Nearest Stars

Astrophotography without a Telescope

Observing Guide for Comet Wilson



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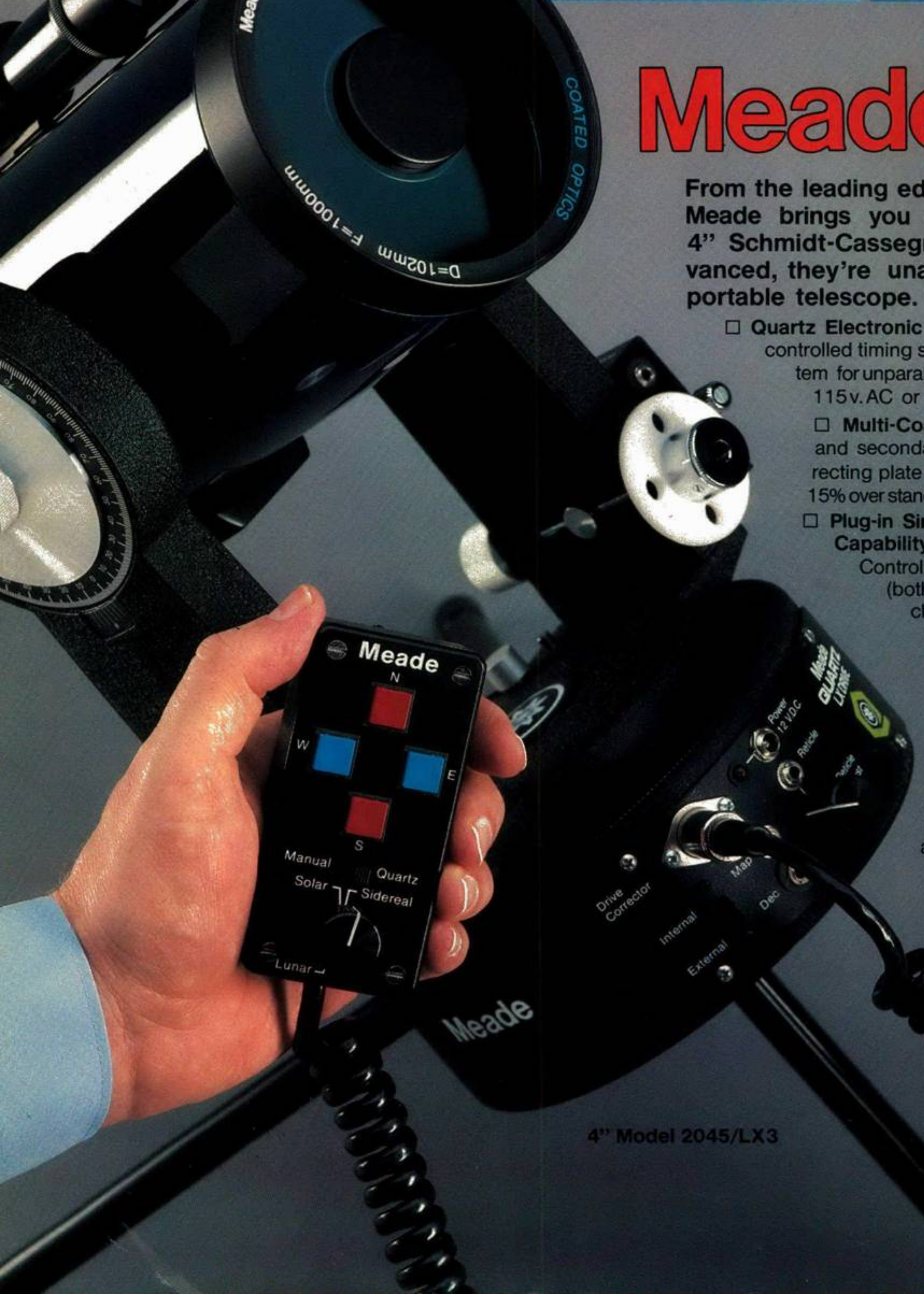
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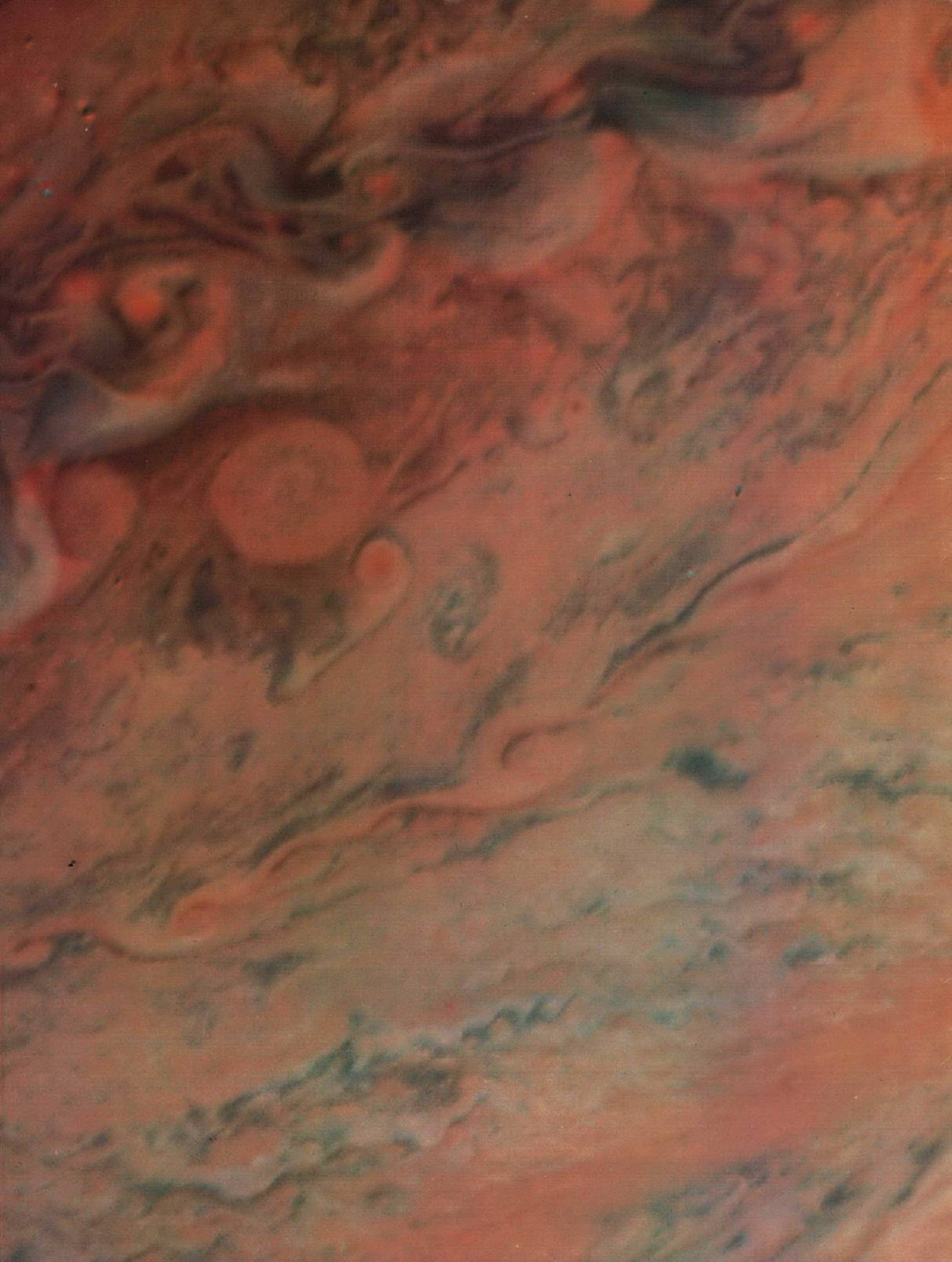

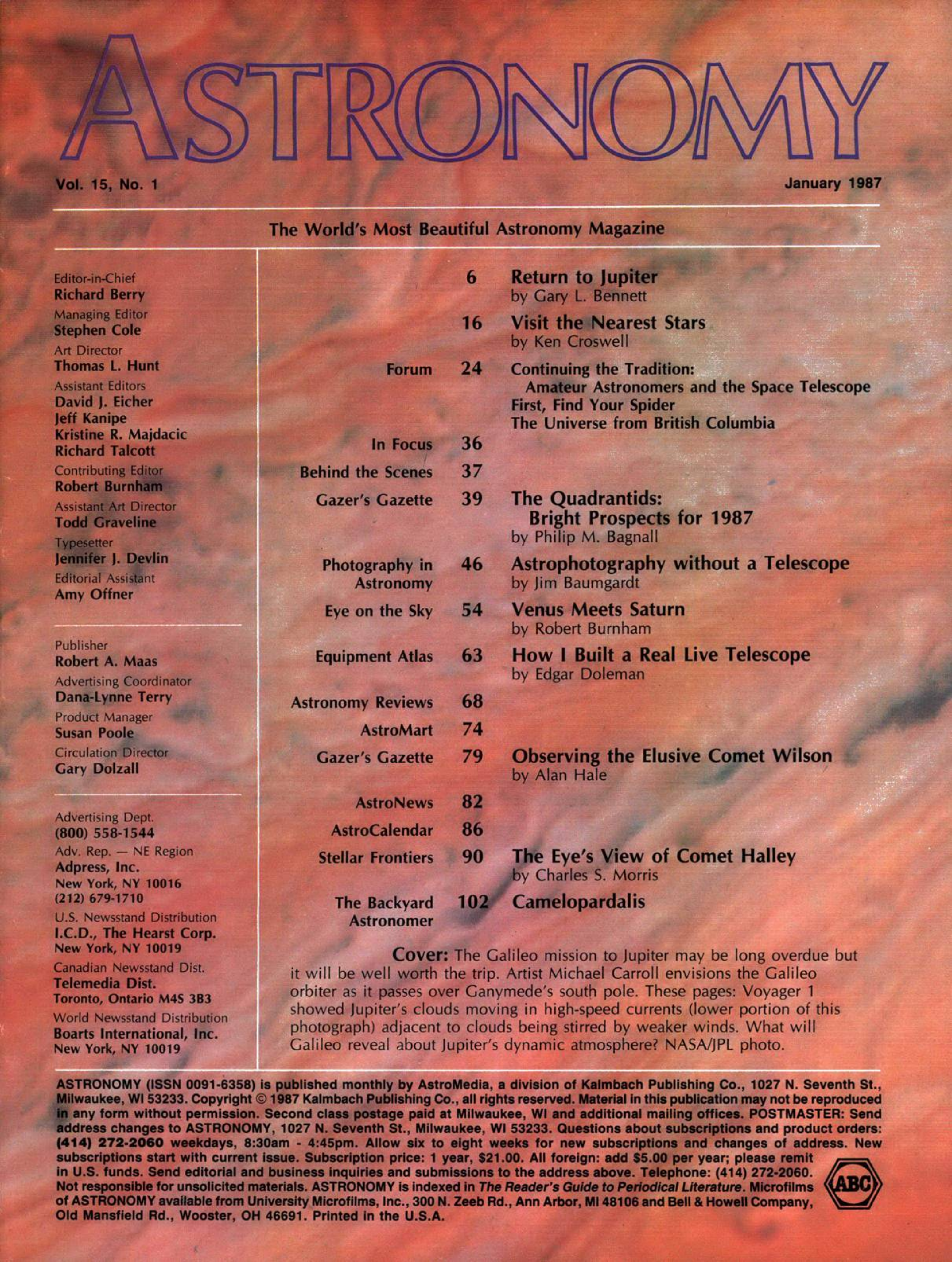

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Cover: The Galileo mission to Jupiter may be long overdue but it will be well worth the trip. Artist Michael Carroll envisions the Galileo orbiter as it passes over Ganymede's south pole. These pages: Voyager 1 showed Jupiter's clouds moving in high-speed currents (lower portion of this photograph) adjacent to clouds being stirred by weaker winds. What will Galileo reveal about Jupiter's dynamic atmosphere? NASA/JPL photo.

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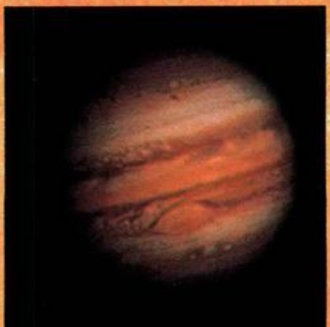
Return to Jupiter

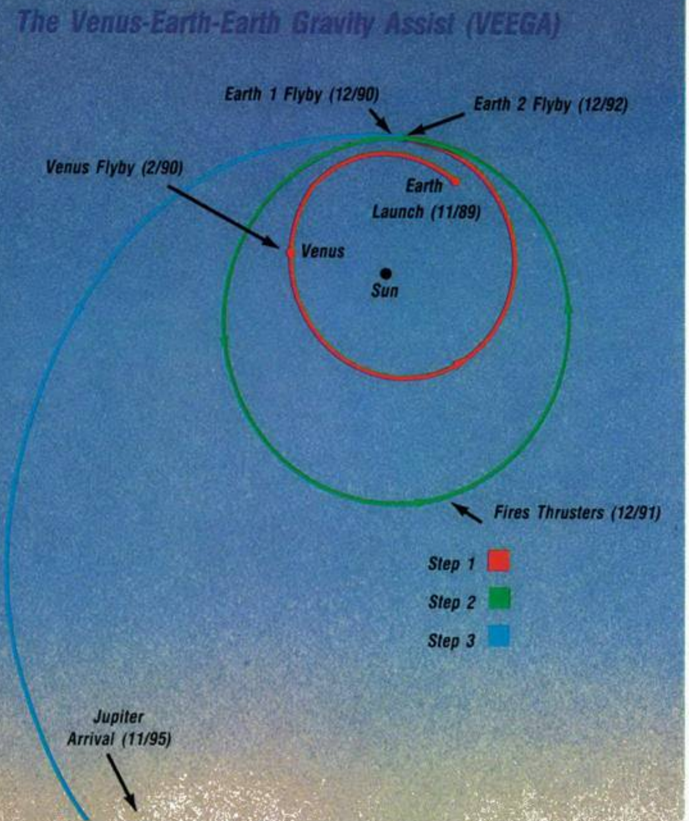
by Gary L. Bennett



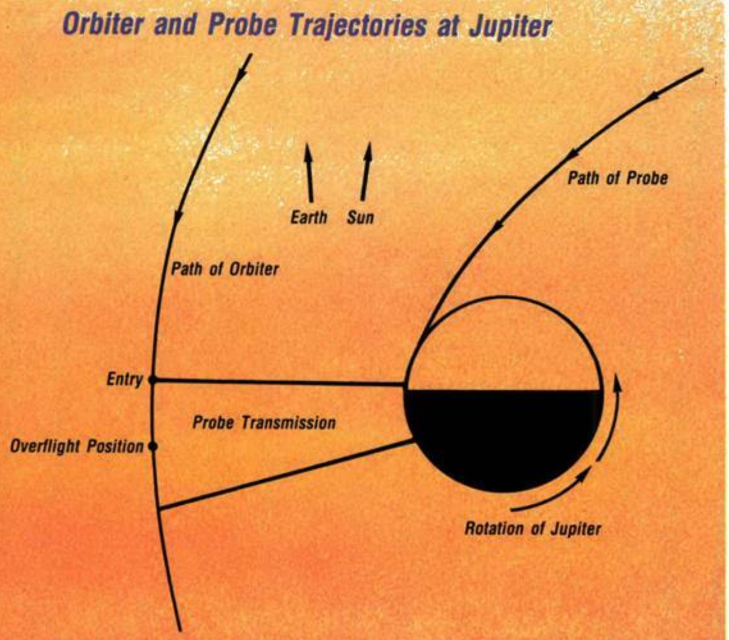
> *"On the seventh day of January in this present year 1610, at the first hour of night, when I was viewing the heavenly bodies with a spyglass, Jupiter presented itself to me; and because I had prepared a very excellent instrument for myself, I perceived. . . that beside the planet there were three starlets, small indeed, but very bright."*
>
> Galileo Galilei

A lot has happened in the 377 years since Galileo documented the first observations of Jupiter's moons in his crude telescope. Technology has progressed to the point where, within the next three years, a spacecraft will be sent to Jupiter to explore and investigate that planet on a scale that has never before been attempted. The mission, appropriately named for Galileo, is designed to make the first long-term study of the giant planet and its retinue of satellites.

In November 1989, if all goes according to current plans, a Space Shuttle will roar into space carrying the Galileo spacecraft on the first leg of its six-year journey to Jupiter. Sometime after the Shuttle achieves orbit, the astronauts will gently eject the spacecraft with its attached Inertial Upper Stage (IUS) booster. The Shuttle will then maneuver out of the way and wait.



The roundabout "VEEGA" trajectory to Jupiter was chosen because it minimizes fuel consumption. It is depicted here in three color-coded steps. Planetary orbits are not plotted. Launch is planned for November 1989, and the first flyby will occur three months later around Venus. Galileo will then loop around the Sun and fly by Earth in December 1990. After this Galileo will once again move around the Sun in a larger loop. In mid-December 1991, approaching its greatest distance from the Sun, Galileo will fire its thrusters to gain an extra 100 meters per second in velocity and to optimize its trajectory for Jupiter. The second Earth flyby will occur in December 1992, when Galileo will speed by at an altitude of only 300 kilometers. This last passage will whip the spacecraft on to its final course for Jupiter. Galileo is expected to arrive in November 1995. NASA/JPL illustration.



One hundred fifty days before its encounter the orbiter will release the atmospheric probe. This trajectory allows the orbiter to be overhead during the probe's descent through Jupiter's atmosphere. NASA/JPL illustration.

About an hour later the IUS's computer will sequentially fire its two stages, thrusting Galileo away from Earth with a peak force of about 276,000 newtons. (A newton is the amount of force required to give a mass of 1 kilogram an acceleration of one meter per second each second.) When the two stages have completed their burns and separated, Galileo will be traveling along a trajectory that will include three planetary flybys (sometimes referred to as the "cruiser" mission) designed to send Galileo to Jupiter with a minimum of propellant.

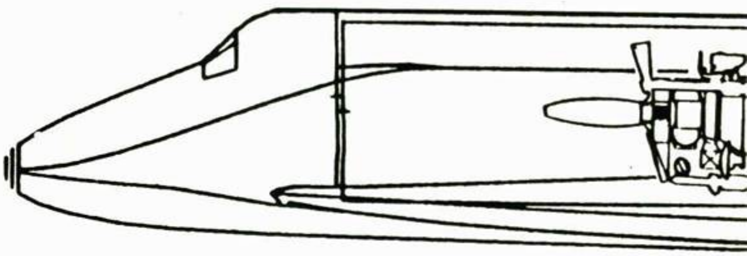
In February 1990, after three months in space, Galileo will sail past Venus at a distance of about 19,400 kilometers to gain more speed for the next phase of its journey. Eight days later the spacecraft will reach its closest approach to the Sun, a little over 106 million kilometers. At this distance the total amount of solar energy falling on the spacecraft will be twice that at Earth. Special sunshades will be added to Galileo to protect its heat-sensitive parts.

After coming round the Sun, Galileo will fly by Earth at an altitude of about 3,600 kilometers in December 1990 on a trajectory that will lead (temporarily) inside Earth's orbit, and then round the Sun again. About a year later Galileo's thrusters will add approximately 100 meters per second to the speed of the spacecraft. This deep-space maneuver will help set up Galileo's trajectory for the earliest encounter with Jupiter.

In December 1992 Galileo will make its second and final pass by Earth. At that time it will be moving at about 14.1 kilometers per second and will pass only 300 kilometers above the surface of Earth.

The cumulative effect of this series of complicated maneuvers, known as the Venus-Earth-Earth Gravity Assist ("VEEGA"), will be to sling Galileo outward along a curving trajectory to intercept Jupiter in November 1995. However, the Galileo scientists and mission planners will also take advantage of the VEEGA trajectory to search for "investigations of opportunity," such as taking measurements around Venus and around any asteroids near the spacecraft's path.

Galileo's flight has been a long time in coming. Originally called the Jupiter-orbiter-probe (JOP) mission, NASA drew up the initial plans before the Voyager launches in 1977. Despite the fact that NASA designated Galileo a top-priority planetary mission, the mission has been plagued by budget cuts and even threatened with cancellation. Delays in meeting the original schedule and lift capacity for Space Shuttle launches affected Galileo's status. Moreover, the spacecraft design had to accommodate several changes in the upper stage. During a nineteen-month period in the early 1980s Congress changed the upper stage from a planned NASA three-



motor version of the Inertial Upper Stage to a Centaur booster specially modified for the Space Shuttle, then to the Air Force two-stage IUS, and then back to the Centaur. At one point there were plans to launch the spacecraft in two separate packages using the three-stage IUS.

The loss of Challenger in January 1986 delayed the launch of Galileo even further, from May 1986 to November 1989. (Galileo was originally planned for launch in January 1982.) The subsequent cancellation of the Centaur program last June sent Jet Propulsion Lab mission planners back to their computers. Given the constraints of funding and scheduling, NASA and JPL have now elected to use the Air Force two-stage IUS coupled with the VEEGA trajectory to compensate for the loss of the more powerful Centaur. In a complete tradeoff, the mission planners have accepted a longer flight time in order to keep Galileo's primary mission at Jupiter intact.

This long, tortured journey will be well worth it. Because Jupiter still contains primordial material from the solar nebula, it is the best cosmological laboratory in the solar system and might hold the key to the origins of our planetary system.

Key to the Early Solar System?

To understand why Jupiter and the outer planets exhibit the characteristics they do today, it is necessary to travel back 4.6 billion years to the beginning of the solar system. Assuming that the composition of the primitive solar nebula was initially uniform, then the differences between the inner terrestrial planets and the outer gaseous planets occurred during the condensation process.

The warm temperatures present in the inner solar nebula kept volatile compounds such as water, ammonia, and methane in a gaseous state. Hence, the planetesimals that would later aggregate into the inner planets formed from nonvolatiles such as iron and silicates. Cooler temperatures in the outer solar nebula, however, allowed volatiles and rocky material to coexist. These became significant components of the giant (Jovian) planets and their moons. Moreover, the greater gravity of the giant planets attracted large quantities of gas from the solar nebula, predominately hydrogen and helium. Above the cloud tops, Jupiter's atmosphere is composed of roughly 90 percent hydrogen and 4.5 percent helium.

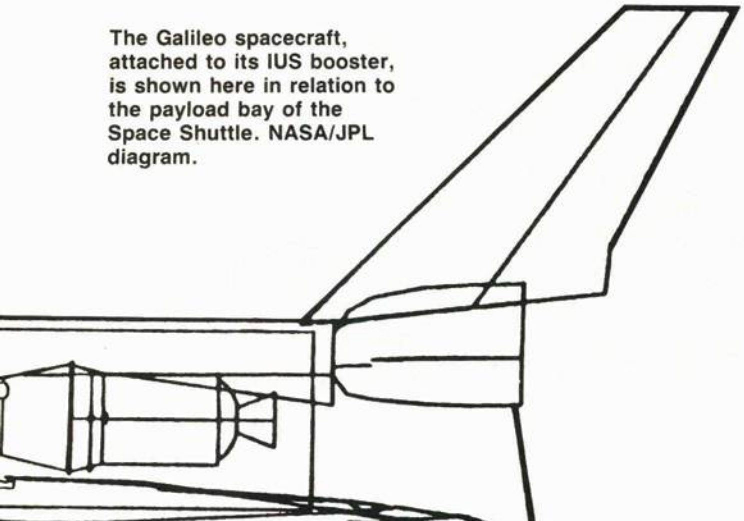
Current theories on the origin of Jupiter propose that the planet emitted a large amount of energy as it gravitationally collapsed. In fact, evidence suggests that at one time Jupiter may have been on its way to becoming a star, although it fell far short of having enough mass. Had Jupiter possessed eighty-five times more mass, the matter at its core might have undergone thermonuclear reactions, and Jupiter would have begun to shine on its own. The solar system would have become a binary system (with probably disastrous consequences for future life on Earth).

Intriguingly, Jupiter has a size near the maximum that a body of cold hydrogen can have without generating its own energy. Bodies less massive than Jupiter would occupy less volume, and those larger would be compressed to a smaller size because of their greater gravity.

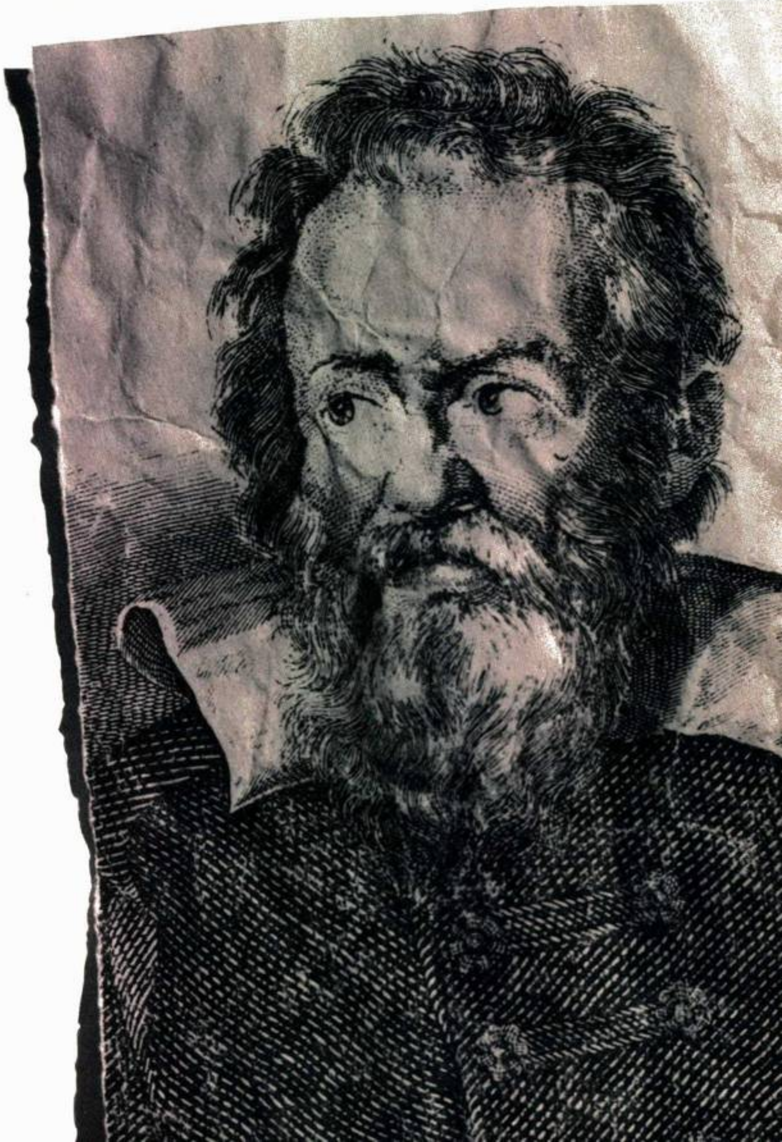
Despite these insights into Jupiter's origin and evolution, there are many more areas that need to be investigated. Whereas the Pioneer and Voyager spacecraft offered researchers only a tantalizing slice of science at Jupiter, the Galileo orbiter and probe will follow up on those previous discoveries and explore new regions as well. As outlined by NASA, the prime objectives of the mission are to investigate the chemical composition and physical state of Jupiter's atmosphere and satellites and to examine the structure and physical dynamics of the Jovian magnetosphere.

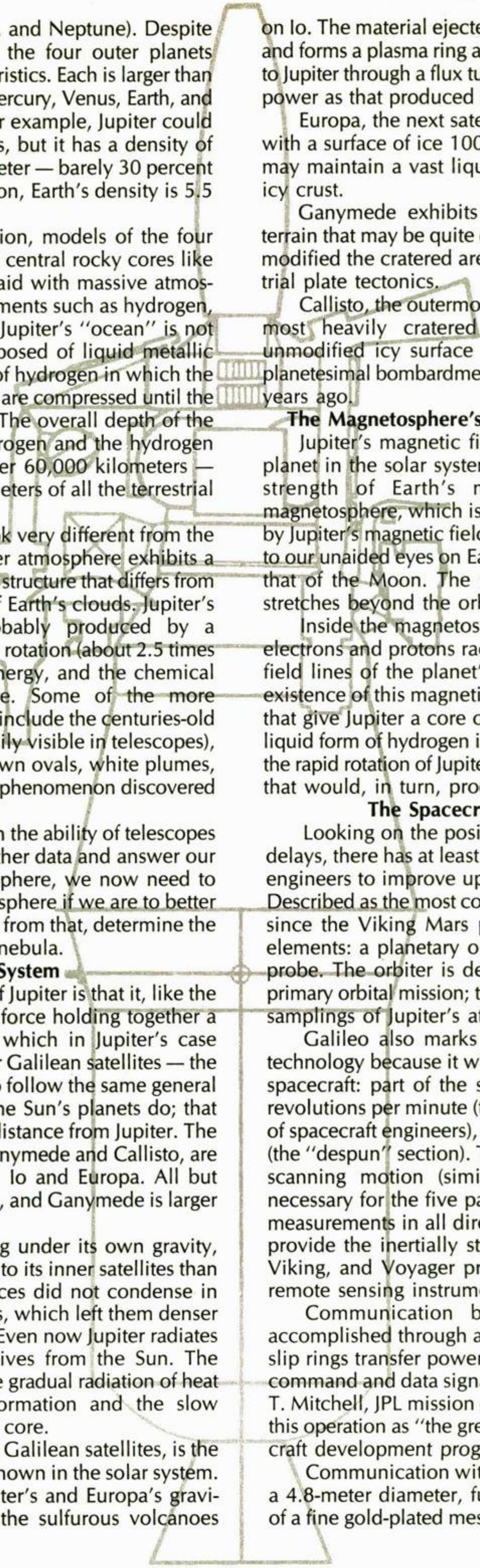
A Deep Atmosphere

At a mean distance of 5.2 astronomical units (AU) from the Sun, Jupiter is nearer to the Earth than the other



The Galileo spacecraft, attached to its IUS booster, is shown here in relation to the payload bay of the Space Shuttle. NASA/JPL diagram.





three gas giants (Saturn, Uranus, and Neptune). Despite the differences between them, the four outer planets exhibit certain common characteristics. Each is larger than the inner, "terrestrial" planets (Mercury, Venus, Earth, and Mars), yet each is less dense. For example, Jupiter could hold the volume of 1,330 Earths, but it has a density of only 1.3 grams per cubic centimeter — barely 30 percent greater than water. By comparison, Earth's density is 5.5 grams per cubic centimeter.

Using this kind of information, models of the four Jovian planets are depicted with central rocky cores like the terrestrial planets, but overlaid with massive atmospheres and oceans of lighter elements such as hydrogen, helium, and other compounds. Jupiter's "ocean" is not water but may instead be composed of liquid metallic hydrogen (a high-pressure state of hydrogen in which the electrons of the individual atoms are compressed until the atomic structure breaks down). The overall depth of the Jovian "ocean" of metallic hydrogen and the hydrogen layer above that is probably over 60,000 kilometers — greater than the sum of the diameters of all the terrestrial planets.

Obviously the gas giants look very different from the terrestrial planets. Jupiter's upper atmosphere exhibits a pronounced and colorful banded structure that differs from the circular or spiral structure of Earth's clouds. Jupiter's variegated atmosphere is probably produced by a combination of the planet's rapid rotation (about 2.5 times faster than Earth), its internal energy, and the chemical composition of its atmosphere. Some of the more prominent atmospheric features include the centuries-old anticyclonic Great Red Spot (easily visible in telescopes), white ovals and spots, large brown ovals, white plumes, and giant lightning discharges, a phenomenon discovered by Voyager 1.

Having reached the limits on the ability of telescopes and orbiting space probes to gather data and answer our questions about Jupiter's atmosphere, we now need to take actual samples of that atmosphere if we are to better understand its composition and, from that, determine the composition of the early solar nebula.

A Mini-Solar System

Another intriguing feature of Jupiter is that it, like the Sun, is the central gravitational force holding together a miniature system of satellites, which in Jupiter's case number at least sixteen. The four Galilean satellites — the largest of Jupiter's moons — also follow the same general pattern of density and size as the Sun's planets do; that is, their density decreases with distance from Jupiter. The outer two Galilean satellites, Ganymede and Callisto, are also larger than the inner two, Io and Europa. All but Europa are larger than the Moon, and Ganymede is larger than Mercury.

The early Jupiter, collapsing under its own gravity, probably provided more energy to its inner satellites than did the early Sun. As a result ices did not condense in the vicinity of the inner satellites, which left them denser and smaller than the outer two. Even now Jupiter radiates twice as much heat as it receives from the Sun. The sources of this energy include the gradual radiation of heat trapped during the planet's formation and the slow gravitational contraction of the core.

Io, the innermost of the four Galilean satellites, is the most volcanically active body known in the solar system. Tidal heating produced by Jupiter's and Europa's gravitational pulls probably drives the sulfurous volcanoes on Io. The material ejected from the volcanoes is ionized and forms a plasma ring about Jupiter. Io is also connected to Jupiter through a flux tube that carries as much electrical power as that produced by all of Earth's power stations.

Europa, the next satellite out, appears to be covered with a surface of ice 100 kilometers thick. Tidal heating may maintain a vast liquid ocean of water beneath this icy crust.

Ganymede exhibits two types of crusts: cratered terrain that may be quite old, and grooved terrain that has modified the cratered areas in a fashion similar to terrestrial plate tectonics.

Callisto, the outermost of the Galilean satellites, is the most heavily cratered of the four. Its apparently unmodified icy surface may still bear the scars of the planetesimal bombardment that occurred about 3.5 billion years ago.

The Magnetosphere's Swarm of Atomic Particles

Jupiter's magnetic field is stronger than that of any planet in the solar system. (It's more than ten times the strength of Earth's magnetic field.) The Jovian magnetosphere, which is the volume of space dominated by Jupiter's magnetic field, is so large that if it were visible to our unaided eyes on Earth, its apparent size would rival that of the Moon. The tail of this vast magnetosphere stretches beyond the orbit of Saturn.

Inside the magnetosphere charged particles such as electrons and protons race around spiral paths along the field lines of the planet's powerful magnetic field. The existence of this magnetic field strongly supports models that give Jupiter a core of liquid metallic hydrogen. The liquid form of hydrogen is electrically conductive. Hence, the rapid rotation of Jupiter would set up electrical currents that would, in turn, produce magnetic fields.

The Spacecraft's Unique Design

Looking on the positive side of the various program delays, there has at least been ample time for the Galileo engineers to improve upon the design of the spacecraft. Described as the most complex spacecraft flown by NASA since the Viking Mars probes, Galileo consists of two elements: a planetary orbiter and an atmospheric entry probe. The orbiter is designed for a twenty-two month primary orbital mission; the probe will make the first direct samplings of Jupiter's atmosphere.

Galileo also marks a major advance in spacecraft technology because it will be the first dual-spin planetary spacecraft: part of the spacecraft will be spinning at 3 revolutions per minute (the "spun" section, in the jargon of spacecraft engineers), while the other part will not spin (the "despun" section). The spun section will provide the scanning motion (similar to the Pioneer spacecraft) necessary for the five particle and field sensors to make measurements in all directions. The despun section will provide the inertially stable platform (like the Mariner, Viking, and Voyager probes) for the camera and other remote sensing instruments.

Communication between the two sections is accomplished through a spin bearing assembly in which slip rings transfer power and rotary transformers transfer command and data signals. William J. O'Neil and Robert T. Mitchell, JPL mission design managers, have described this operation as "the greatest difficulty in the entire spacecraft development program."

Communication with Earth will be achieved through a 4.8-meter diameter, furlable, high-gain antenna made of a fine gold-plated mesh and supported by an umbrella-

Jupiter Data Table

Mean Distance from the Sun	*778.3 million kilometers (5.203 AU)*
Equatorial Diameter	*142,800 km*
Mass	*317.83 Earth masses*
Density	*1.33 times that of water*
Gravity	*2.54 times that of Earth*
Temperature	*−173°C at cloud tops*
Escape Velocity	*59.6 km/s*
Rotation Period at the Equator	*9h 50m 30s*
Revolution Period	*11.86 years*
Mean Orbital Velocity	*13.06 km/s*
Number of Known Satellites	*16*

Galilean Satellites

Io

Diameter	*3,630 km*
Orbital Radius	*421,600 km*
Orbital Period	*1.7 days*

Europa

Diameter	*3,140 km*
Orbital Radius	*671,900 km*
Orbital Period	*3.5 days*

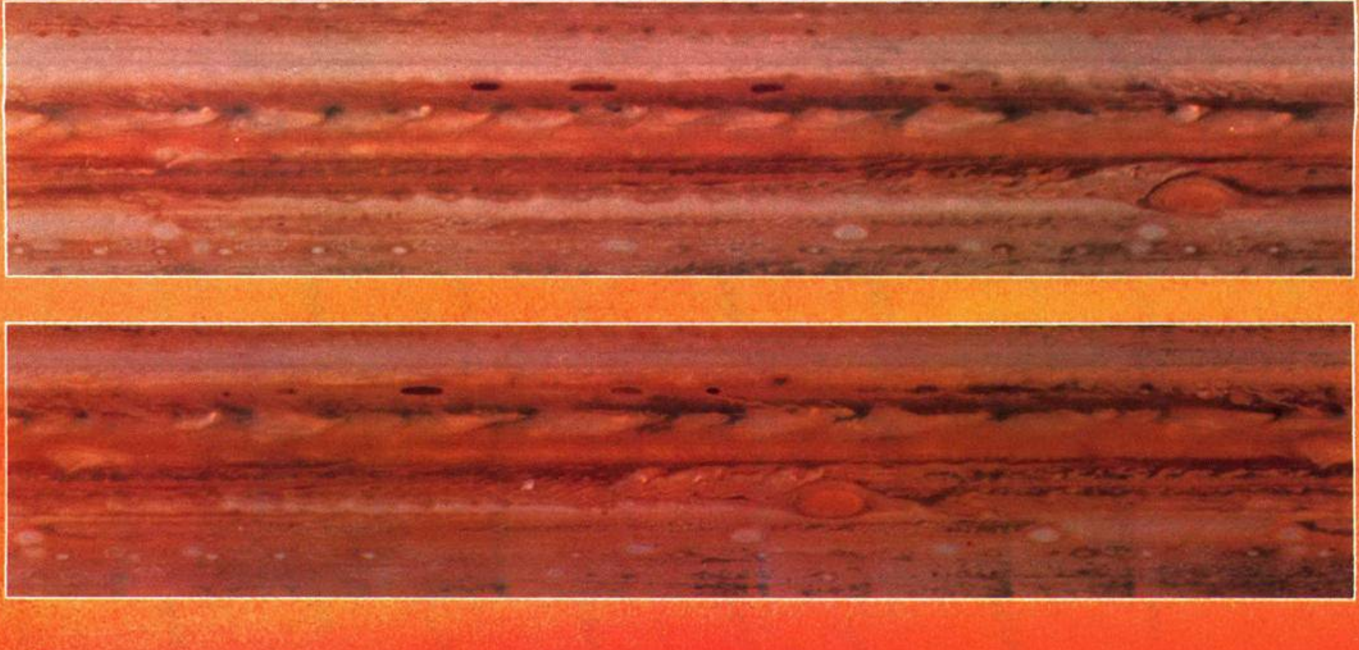
Ganymede

Diameter	*5,260 km*
Orbital Radius	*1,070,000 km*
Orbital Period	*7.1 days*

Callisto

Diameter	*4,800 km*
Orbital Radius	*1,881,000 km*
Orbital Period	*16.6 days*

These cylindrical projections from Voyager 1 (top) and Voyager 2 (bottom) show the relative motions of Jupiter's cloud features north and south of the equatorial zone. The photos have been aligned so that the longitude scale is the same for both frames. In the time between missions, the Red Spot shifted westward and the white oval features moved eastward. Note, too, the subtle changes in circulation east and west of the Red Spot. NASA/JPL photos.

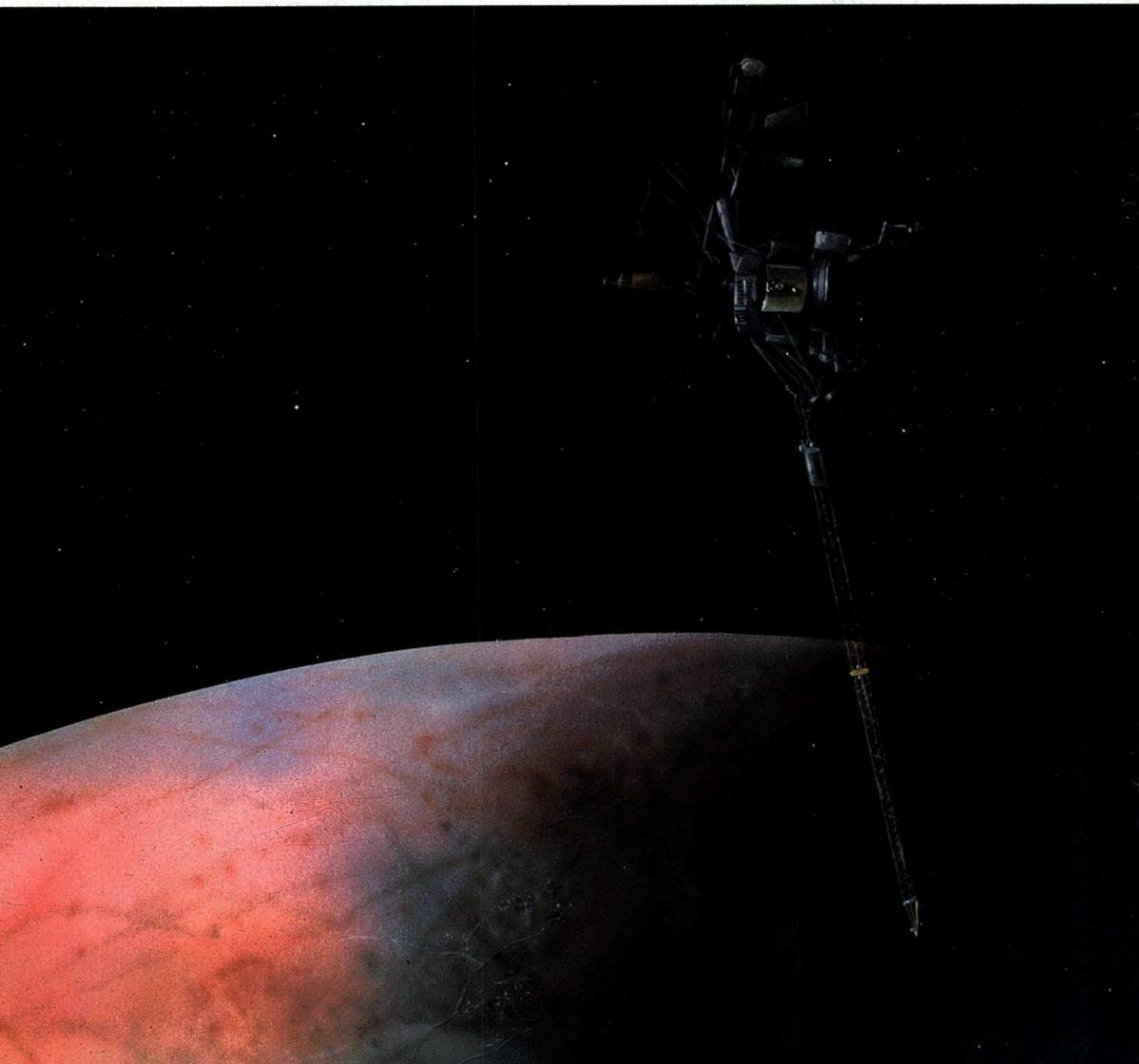


like structure. Because of the low melting point of gold, the high-gain antenna will remain stowed and protected by a sunshade until it is over 1 AU from the Sun. Galileo is capable of transmitting data at a maximum rate of 134 kilobits per second at the X-band frequency (8,415 MHz). Transmission of telemetry data on the S-band (2,295 MHz) is also available.

Nineteen microprocessors aboard Galileo control the various subsystems and scientific instruments. They, in turn, communicate with the Command and Data Subsystem (CDS) over a data bus (a set of electrical conductors that relays data from one system to another). All of Galileo's programs accept commands from Earth and most are completely reprogrammable. Within this complex of microprocessors, the CDS acts as supervisor and coordinator for all major spacecraft functions. It also communicates with the Attitude and Articulation Control Subsystem (AACS), which is responsible for determining the spacecraft's orientation, propulsion control, and scan platform articulation control. The majority of the orbiter electronics are located within an eight-sided spun bus next to the high-gain antenna.

Galileo's electronic components are hardened, or shielded, to protect them against the strong radiation fields around Jupiter. High energy charged particles (such as electrons and protons) can penetrate and change the logic state of a memory cell. This phenomenon, called single-event upset (SEU), has been observed on the Tracking and Data Relay Satellite-1 in Earth orbit. The radiation levels around Jupiter are even worse. SEUs on Galileo could lead to erroneous commands and loss of valuable data.

The hardened chips must be able to withstand a dose of 150,000 rads with high reliability. (A rad is a measure of the amount of energy absorbed in a given mass of material.) One rad equals 100 ergs per gram. Typical exposures are 0.045 rad for a chest x-ray and 1.1 rad for



a single dental x-ray. A dose above 600 rads is lethal to humans. In its brief flight through the Jovian system, Pioneer 10 received a dose of 56,000 rads from protons and 200,000 rads from electrons. So much for science fiction scenes of astronauts cavorting unshielded around the satellites of Jupiter!

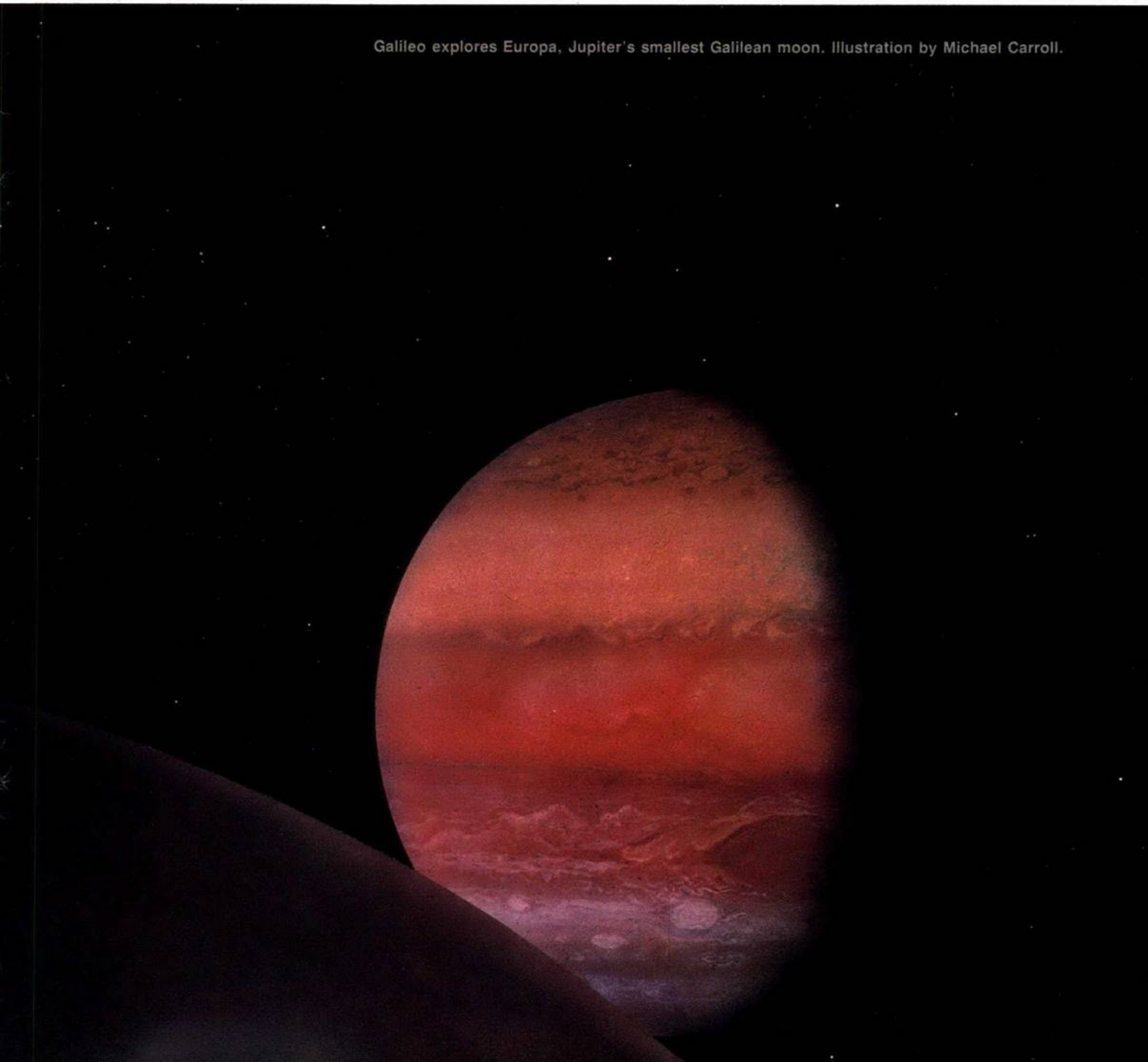
Included among the orbiter's nine scientific instruments is an 800-line by 800-element charge-coupled device (CCD). The CCD is over one hundred times as sensitive as the TV vidicom tubes used by Voyagers 1 and 2. Fantastic resolution, in some cases on the order of meters, is expected from the Galileo images.

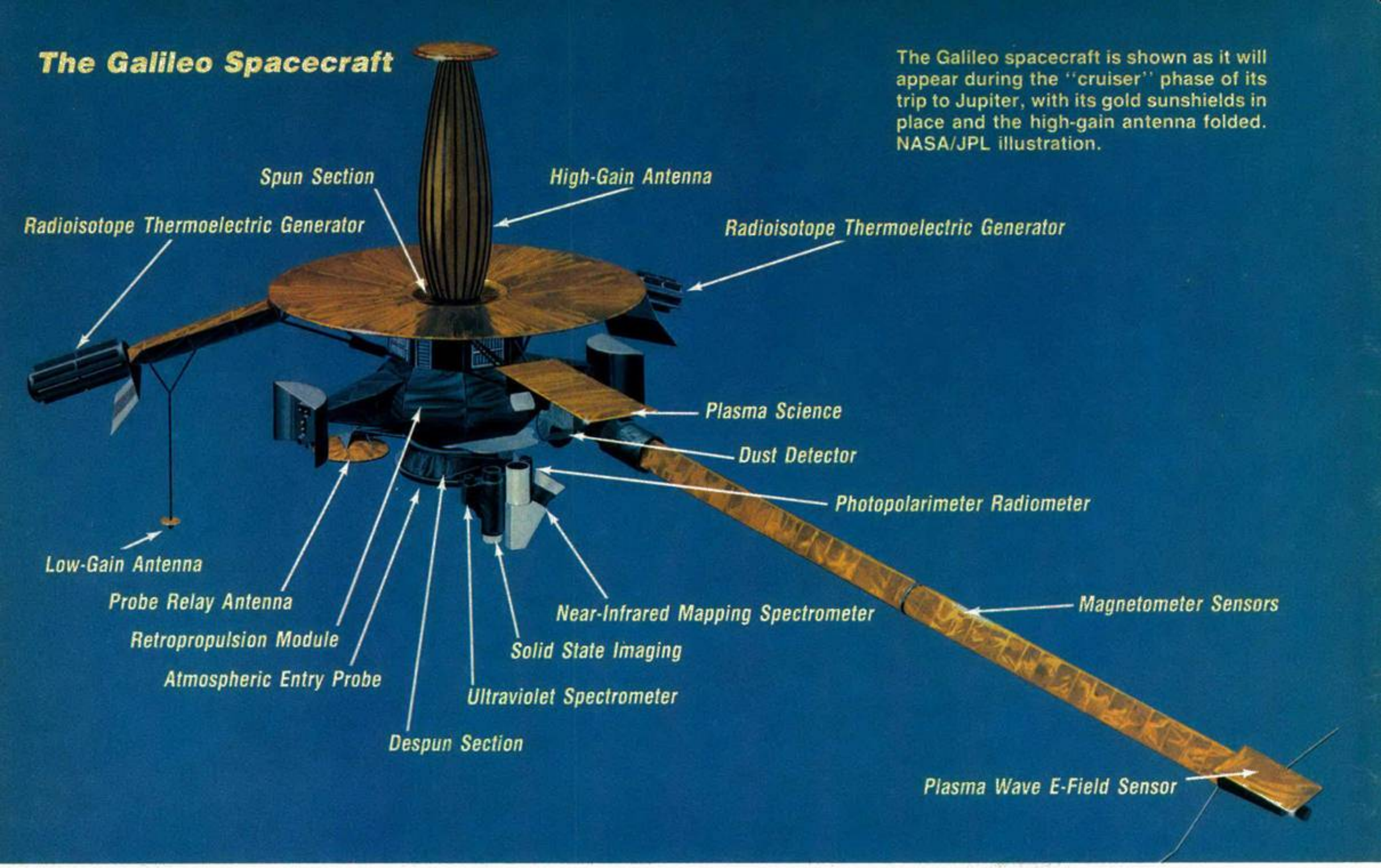
Other instruments include:

- a near-infrared mapping spectrometer, which will provide infrared images and measure the reflected sunlight and heat emission from Jupiter's atmosphere and satellites;
- an ultraviolet spectrometer for analyzing the atmosphere of Jupiter and its satellites;
- a photopolarimeter radiometer for measuring the temperatures of Jupiter's atmosphere and of the satellite's surfaces;
- a magnetometer for measuring the strength and changes in the Jovian magnetic field as well as searching for magnetic fields associated with the satellites;
- plasma and plasma-wave instruments to study the properties of the plasmas around Jupiter;
- an energetic-particle detector for measuring the composition, distribution, and energy spectra of high-energy particles (ions, electrons, and protons);
- a dust detection instrument for measuring the size, speed, and charge of dust particles near Jupiter and its satellites.

Radio equipment will make additional measurements of Jupiter's atmosphere as well as Jovian and solar gravitational fields and extra-solar gravitational radiation.

Galileo explores Europa, Jupiter's smallest Galilean moon. Illustration by Michael Carroll.





The Galileo Spacecraft

The Galileo spacecraft is shown as it will appear during the "cruiser" phase of its trip to Jupiter, with its gold sunshields in place and the high-gain antenna folded. NASA/JPL illustration.

All instruments will be calibrated and the solar wind will be sampled during the Earth-to-Jupiter cruise phase.

Power for the Galileo orbiter is provided by two radioisotope thermoelectric generators (RTGs), each mounted on separate 5-meter long booms. The RTGs produce 570 watts of total power at the beginning of the mission but decrease as the mission progresses. Heat for temperature-sensitive instruments will be provided by 101 one-watt radioisotope heater units (RHUs) — sixty-seven in the orbiter and thirty-four in the probe. Nuclear power is the only choice for long-duration missions well beyond Mars' orbit, where the solar energy flux is less than 4 percent that at Earth.

After separating from the IUS, the propulsion functions for Galileo will be provided by the Retropropulsion Module (RPM) located on the orbiter's spun side. The RPM consists of four propellant tanks (two fuel and two oxidizer tanks) with 932 kilograms of usable propellant, two helium pressure tanks, twelve 10-newton thrusters (six each mounted on separate cantilevered booms), one single 400-newton engine, and the required isolation and control elements. The RPM will provide all directed thrusts for attitude control, trajectory correction, and Jupiter orbit insertion.

The thrusters provide a total velocity change, or delta V, of about 1.5 kilometers per second, which must accommodate all maneuvers from launch to the end of the mission. Of this, only about 0.2 kilometers per second delta V is allocated for the tour of Jupiter. However, the planned twenty-two month tour requires over 6 kilometers per second of spacecraft delta V — clearly beyond the capability of the RPM. The solution lies in the orbiter's ability to use gravity assists from the Galilean satellites to make major changes in period and orientation of the orbit.

The Probe's Descent to Jupiter

The atmospheric probe, located in the despun section of Galileo, consists of two major elements: a deceleration module and a descent module. The deceleration module includes the heat shields that are designed to protect the scientific instruments during the fastest atmospheric entry of any manmade craft. Almost two-thirds of the shield material will burn off during atmospheric entry.

The descent module contains six instruments designed to study the Jovian atmosphere. These include an atmospheric instrument to provide information on the temperature, density, and pressure within Jupiter's atmosphere; a neutral mass spectrometer for measuring the composition of atmospheric gases; and a helium-abundance interferometer to determine the ratio of hydrogen to helium. Still other instruments will study cloud particles, atmospheric lightning, and energetic particles.

Approximately five months before encounter the orbiter will provide final targeting and spin-up for the probe, since it has no thrusters for maneuvering or attitude control. The spacecraft will first maneuver onto a precise, ballistic-entry trajectory. Then the spacecraft will spin up to 10 rpm and release the now stabilized probe to fly on a trajectory designed to intercept the Jovian atmosphere at a relative flight path angle between −7.0 degrees and −10.2 degrees, an extremely shallow entry path. An angle any shallower would cause the probe to skip out of Jupiter's atmosphere; any steeper angle would produce high aerodynamic forces that would no doubt destroy the probe.

The probe has been extensively tested to ensure that it will survive the high atmospheric entry temperatures (up to 40 kilowatts per square centimeter, which is nearly seven times as much thermal power emitted by each square centimeter of the surface of the Sun!), and the high-entry deceleration (perhaps up to 345 g for a worst-case entry).

Three days after releasing the probe the orbiter will fire its 400-newton engine for the first time to place it on a trajectory to fly over the probe as it descends into the Jovian atmosphere.

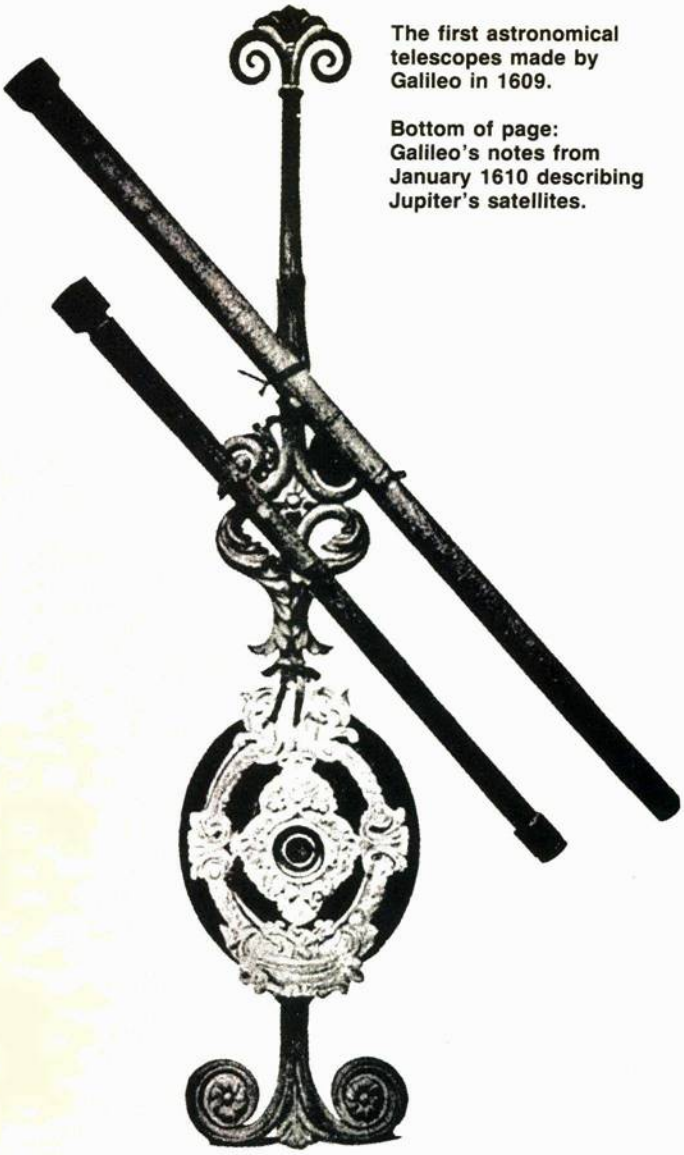
In November 1995 the Galileo probe and orbiter will arrive at Jupiter. The orbiter will shoot past volcanic Io at a distance of 1,000 kilometers — twenty times closer than the closest Voyager approach. The gravity of Io will slow the orbiter.

Four hours later the probe will tear into the Jovian atmosphere 450 kilometers above the cloud deck, just north of the equator. Its entry speed will be about 48 kilometers per second. Fortunately the probe will be entering the atmosphere in the same direction as the planet rotates, which reduces the entry speed and lessens the amount of frictional heat on the shield. Still, heating will be considerable: during the first twenty seconds the temperature of the gas layer around the probe is expected to reach 8,300° Celsius. Nearly two minutes later, after the strongest deceleration has passed, the descent module will be drifting down into the Jovian atmosphere under a Dacron parachute.

As it descends, the probe will make its atmospheric measurements and transmit the data to the orbiter. The orbiter in turn will relay the data to Earth in real time. Roughly one hour after entry the probe will be below the cloud deck, but rising pressures and temperatures will combine with a degraded radio link to cause a major loss of data. Although this will be the end of the primary data transmission, the orbiter, as programmed, will "listen" to the probe for another fifteen minutes for any information it might still be able to relay.

Immediately after the probe mission the orbiter will fire its engine for almost an hour to put it into the first of eleven orbits about Jupiter. For the next twenty-two months the orbiter will carry out its primary orbital mission, making close passes by Europa, Ganymede, and Callisto, and add immeasurably to our understanding of the Jovian system. (Galileo is scheduled to fly by Io only once due to the intense radiation belts in Jupiter's inner satellite system. Additional flybys would be dependent on the condition of the spacecraft.)

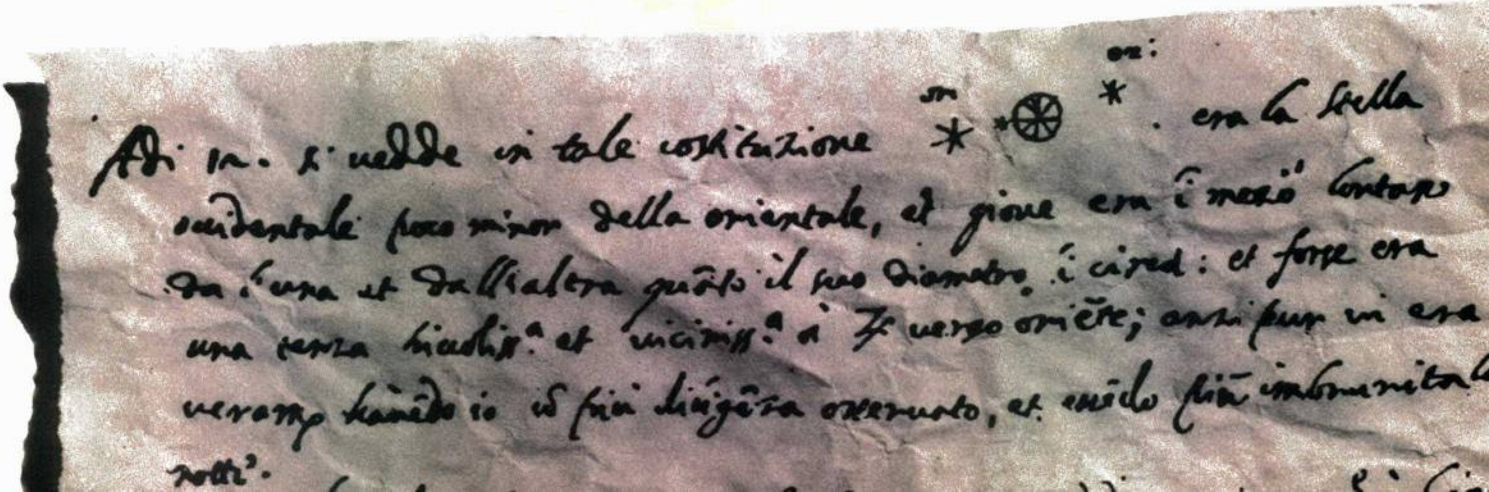
The amount of science we can expect from the Galileo mission will make our return trip to Jupiter well worth the effort, not to mention establishing more "firsts" for the space program to rally around. As mission design managers O'Neil and Mitchell stated: "Project Galileo stands at the threshold ready to revitalize the U.S. Solar System Exploration Program. The major obstacles that caused the many delays in Project Galileo have been overcome. . . . Galileo will be the first mission in history to send a probe into an outer planet atmosphere, and the first to place a spacecraft in orbit about an outer planet."



The first astronomical telescopes made by Galileo in 1609.

Bottom of page: Galileo's notes from January 1610 describing Jupiter's satellites.

Gary L. Bennett is the Deputy Director of the Division of Special Applications at the U.S. Department of Energy. For over ten years he has been working on space propulsion and power systems including both the Ulysses and Galileo missions.



Adì 12. si vedde in tale costituzione * *⊛ * . era la stella
occidentale poco minor della orientale, et giove era i mezo lontano
da l'una et dall'altra quanto il suo diametro i circa: et forse era
una terza picolis.a et vicinis.a à ♃ verso oriẽte; anzi pur vi era
veramẽ havendo io cõ più diligẽza osservato, et essendo più imbrunita la
notte.

VISIT THE NEAREST STARS

BY KEN CROSWELL

Distances to the Twenty Closest Stars

0 ly
THE SUN
Spectral type: G2
Mass: 1.0 $M_{\odot}$

●	PROXIMA CENTAURI	4.2 ly
●●	ALPHA CENTAURI	4.3 ly
●	BARNARD'S STAR	6.0 ly
●	WOLF 359	7.7 ly
●	LALANDE 21185	8.2 ly
●●	LUYTEN 726-8	8.4 ly
●●	SIRIUS	8.6 ly
●	ROSS 154	9.4 ly
●	ROSS 248	10.4 ly
●	EPSILON ERIDANI	10.8 ly
●	ROSS 128	10.9 ly
●●	61 CYGNI	11.1 ly
●	EPSILON INDI	11.2 ly
●	LUYTEN 789-6	11.2 ly
●●	GROOMBRIDGE 34	11.2 ly
●●	PROCYON	11.4 ly
●●	Σ2398	11.6 ly
●	LACAILLE 9352	11.7 ly
●	G 51-15	11.7 ly
●	TAU CETI	11.8 ly

By the end of this decade the United States will have sent spacecraft past all the planets of the solar system from Mercury to Neptune. Four spacecraft are leaving the solar system, venturing toward the stars beyond. It is now time to start thinking of exploring the stars — of sending probes to the pinpoints of light dotting the night sky.

Compared with the Sun and planets, though, stars are enormously distant. If the space between the Sun and Earth were reduced to 1 inch, Neptune would be nearly 30 inches from the Sun. Yet the nearest star would be over 4 miles away, lying over 9,000 times farther from the Sun than Neptune. The fastest spacecraft made by humans to date — Voyager 1 — will require tens of thousands of years just to reach the Proxima and Alpha Centauri system, the star system nearest our own. Because of these vast distances our exploration will obviously be limited to those stars closest to the Sun.

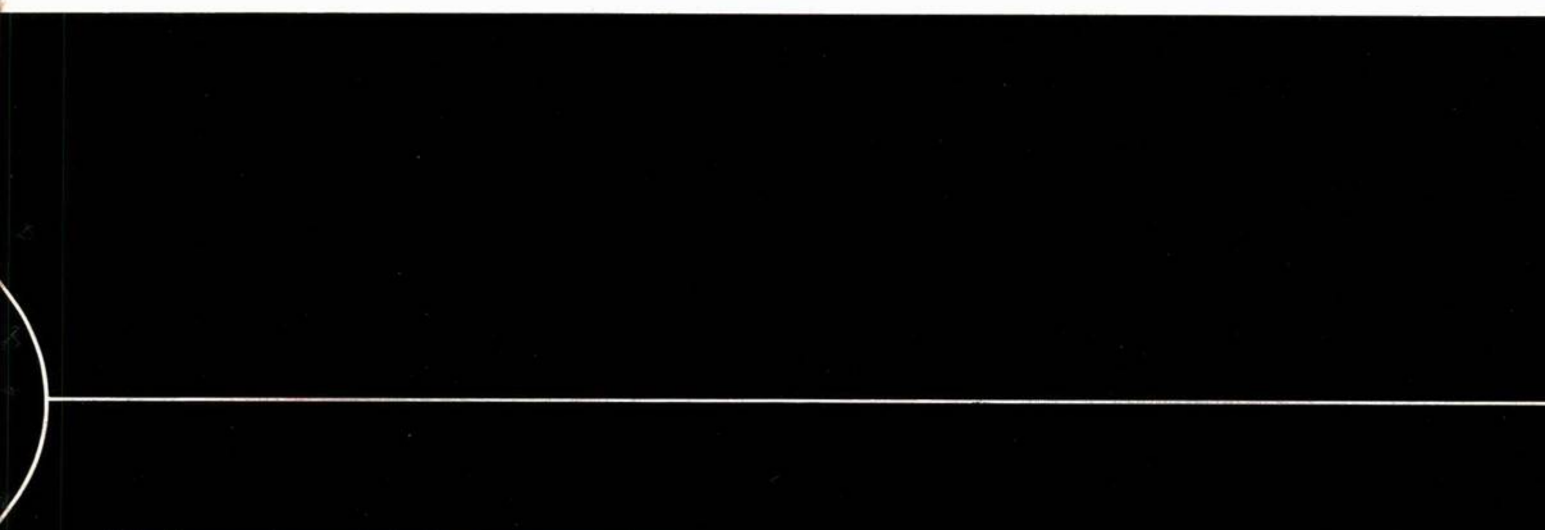
The stars in our vicinity of the Galaxy form a diverse group, ranging from tiny red dwarfs to bright white stars. Some of these stars are young, some old; some are variable, others stable. Many probably have orbiting planets, and a few of these planets may be supporting life on their surfaces.

What Can Nearby Stars Tell Us?

The nearest stars represent the most unbiased available sample of stars inhabiting the Galaxy. Therefore, by observing them, we can conduct a stellar census that reveals important information about stars in general. We can then determine which types of stars are most common and find the average stellar luminosity and mass.

How does our Sun compare with other stars? Is it brighter than most or dimmer? Is it more massive or less? It's only from surveying the nearest stars that we have been able to answer these questions.

Astronomers also value the nearest stars because they can measure the distances of these stars precisely and can therefore deduce their absolute magnitudes and luminosities. (Most of the stars that appear bright in the sky are quite distant, so we have less reliable information about them.) We can also determine the velocities of the nearby stars through space, providing information on the motions of objects throughout the entire Milky Way



This diagram shows relative linear distances for the stars within 12 light-years; relative star sizes are shown on a different scale. Diagram by David J. Eicher.

Galaxy.

Most of the stars in the Galaxy are main-sequence stars. A *main-sequence* star converts hydrogen into helium in its core, thereby generating energy that is converted into light and heat. The Sun is a main-sequence star, as are about 90 percent of all known stars.

But main-sequence stars come in all masses, from 0.085 solar masses ($M_\odot$) to about 100 $M_\odot$. The more massive a main-sequence star is, the brighter it is. For example, a star twice as massive as the Sun shines nearly twenty times more brightly. So, although a 2 $M_\odot$ star has twice as much fuel, it burns that fuel twenty times faster than the Sun. Thus, its total lifetime is only one-tenth that of the Sun. Since the Sun's lifetime is expected to be 10 billion years, a 2 $M_\odot$ star's life expectancy is only about 1 billion years.

With the main-sequence stars, increased mass also means higher temperature, and this in turn causes bluer color. Astronomers classify stars into seven main spectral classes by color: O, B, A, F, G, K, and M. O stars are very hot, blue, and bright. They range in mass from 16 to 100 $M_\odot$. Because they shine so brightly, they exist for only a few million years. B-type stars are also blue but range in mass from 2.5 to 16 $M_\odot$. Regulus, the brightest star in Leo, is a B main-sequence star.

A-type stars are white, ranging in mass from 1.6 to 2.5 $M_\odot$. Included among the ranks of A-type stars are the bright stars Vega and Fomalhaut. F stars are yellow-white with masses between 1.05 and 1.6 $M_\odot$. G stars are yellow and range in mass from 0.9 to 1.05 $M_\odot$. The Sun is a G-type star.

Cooler and dimmer than these are K stars, which glow with an orange color and have masses between 0.6 and 0.9 $M_\odot$. M-type stars are the faintest and coolest main-sequence stars, so they are often called red dwarfs. They range in mass from 0.085 to 0.6 $M_\odot$.

For further precision astronomers divide each spectral class into ten subclasses. Spectral type G, for instance, breaks into G0, G1, G2, G3 and so on up to G9. A G0 star is slightly hotter than a G1 star, which is slightly hotter than a G2 star. Our Sun is a type-G2 star.

We've uncovered four laws that govern the lives of main-sequence stars. The more massive a main-sequence star is, 1) the brighter it is; 2) the hotter it is; 3) the bluer it is; and 4) the shorter its lifetime.

Not all stars are main-sequence stars, however. Some stars are so young that they haven't yet reached the main sequence; these are the pre-main-sequence stars, which do not yet convert hydrogen into helium. Other once-main-sequence stars are so old that they have consumed their fuel and expanded into red giant stars, which no longer radiate energy by the hydrogen-into-helium process. Red giants are bright, red, and cool. And, when a red giant dies, the star usually becomes a white dwarf star, an object with the mass of the Sun but the diameter of Earth. Finally, very low mass stars — those less massive than 0.085 $M_\odot$ — never get hot enough to ignite their hydrogen and thus never reach the main sequence. These stars are called brown dwarfs or black dwarfs and, because they are so faint, we know only a few stars that may belong to this class.

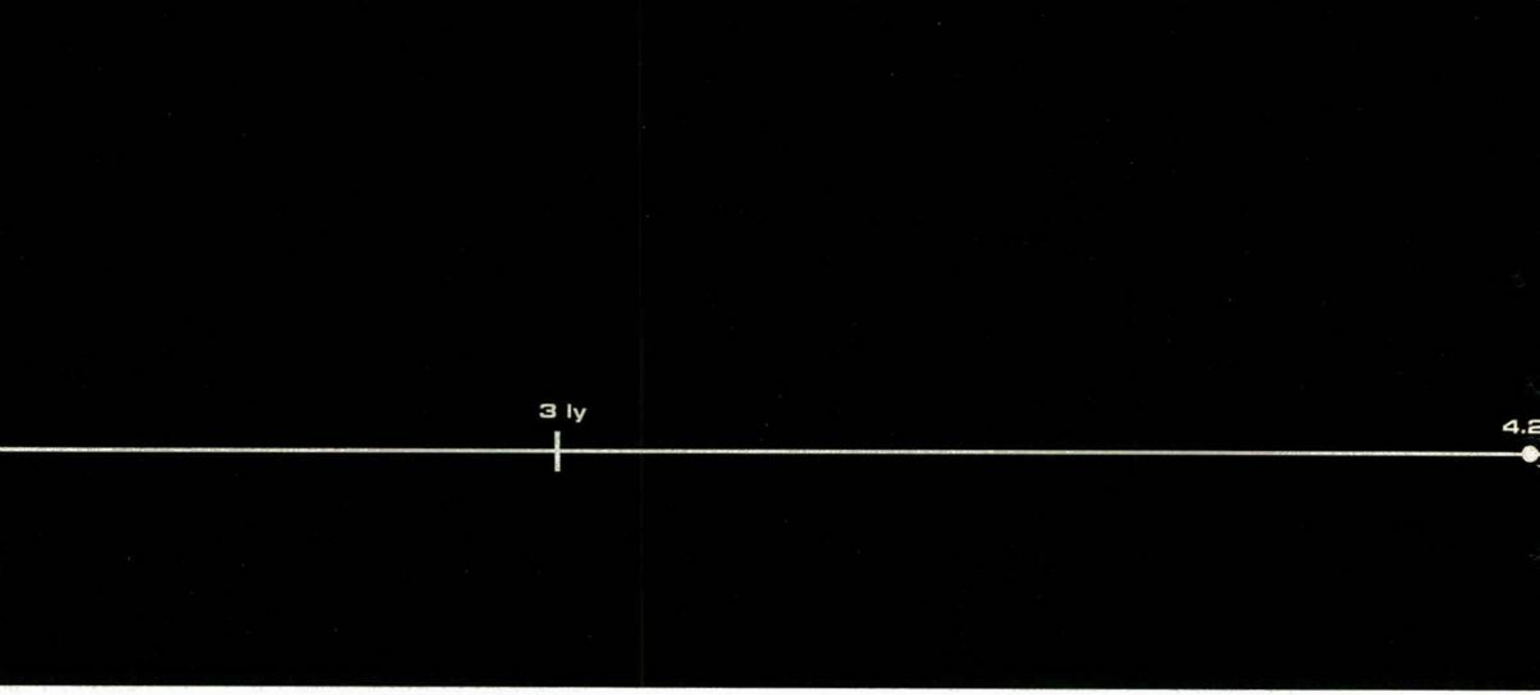
The Sun is a main-sequence star with an age of 4.5 billion years, a spectral type of G2 and, of course, a mass of 1.00 $M_\odot$. Its absolute magnitude — that is, the apparent magnitude it would have if it were 10 parsecs (32.6 light-years) away — is +4.85. Contrary to popular belief, these properties make the Sun a very "unaverage" star. If you don't believe it, just wait until we've visited the other nearby stars.

A Journey from the Solar System

Let's embark on our tour of the Sun's nearest neighbors. We'll visit nineteen star systems out to a radius of nearly 12 light-years and see an enlightening mix of different types of stars.

The first stop beyond the Sun is Alpha Centauri, 4.3 light-years away. Alpha Centauri is not a star but a star system. It consists of three separate stars orbiting a common center of mass. Star systems containing more than one star are called multiple-star systems. Although such arrangements may seem strange to us (our Sun is single, after all), most stars in the Galaxy — perhaps two-thirds of them — are actually members of multiple star systems.

The three stars in the Alpha Centauri system are very different from one another. The brightest star, Alpha Centauri A, is a yellow G-type star, whereas Alpha



Centauri B is an orange K-type star, and Alpha Centauri C is a dim red M-type dwarf. Alpha Centauri A and B orbit each other with an average separation of 23 astronomical units and a period of 80 years. Alpha Centauri C orbits this pair at a distance of 12,000 AU. Of the three stars, Alpha Centauri C is currently the closest to our solar system, so astronomers often call it Proxima Centauri.

Alpha Centauri A has a mass of 1.11 $M_\odot$ and an absolute magnitude of +4.37, so it is slightly brighter and more massive than the Sun. Yet its spectral type is G2, the same type as the Sun. A 1.11 $M_\odot$ main-sequence star should have a spectral type of F8 or F9, not G2, which suggests that Alpha Centauri A is so old that it has begun to evolve off the main sequence. Following this line of reasoning, astronomers Brian Flannery of Exxon Corp. and Thomas Ayres of the University of Colorado estimated in 1978 that Alpha Centauri A is about 6 billion years old — slightly older than the Sun. A similar study published in 1986 by researchers Pierre Demarque, D. B. Guenther, and William van Altena of Yale University suggested that the star is about the same age as the Sun.

Yet Proxima Centauri is a flare star, a red dwarf that unpredictably erupts and, for a few minutes at a time, attains a brightness much greater than normal. Such activity is a sign of youth, and most flare stars are only 1 or 2 billion years old. If Alpha Centauri A and B are really 4 to 6 billion years old, and if Proxima Centauri is only 1 or 2 billion years old, there is only one explanation for its relative youth: Proxima Centauri did not form with Alpha Centauri A and B but was captured by them sometime in the last billion years or so.

Because Alpha Centauri A is Sun-like, it may be able to support life — *if* it has orbiting planets. But planetary systems cannot form around all binary stars. If the two stars in a binary are separated by a large distance, each star could have its own solar system and not interfere with the other's environmental conditions as the stars orbit. If the two stars are instead very close together, then a single planetary system could exist around the pair. Unfortunately, Alpha Centauri A and B fall between these two extremes, and many astronomers do not believe a solar system could have formed around them.

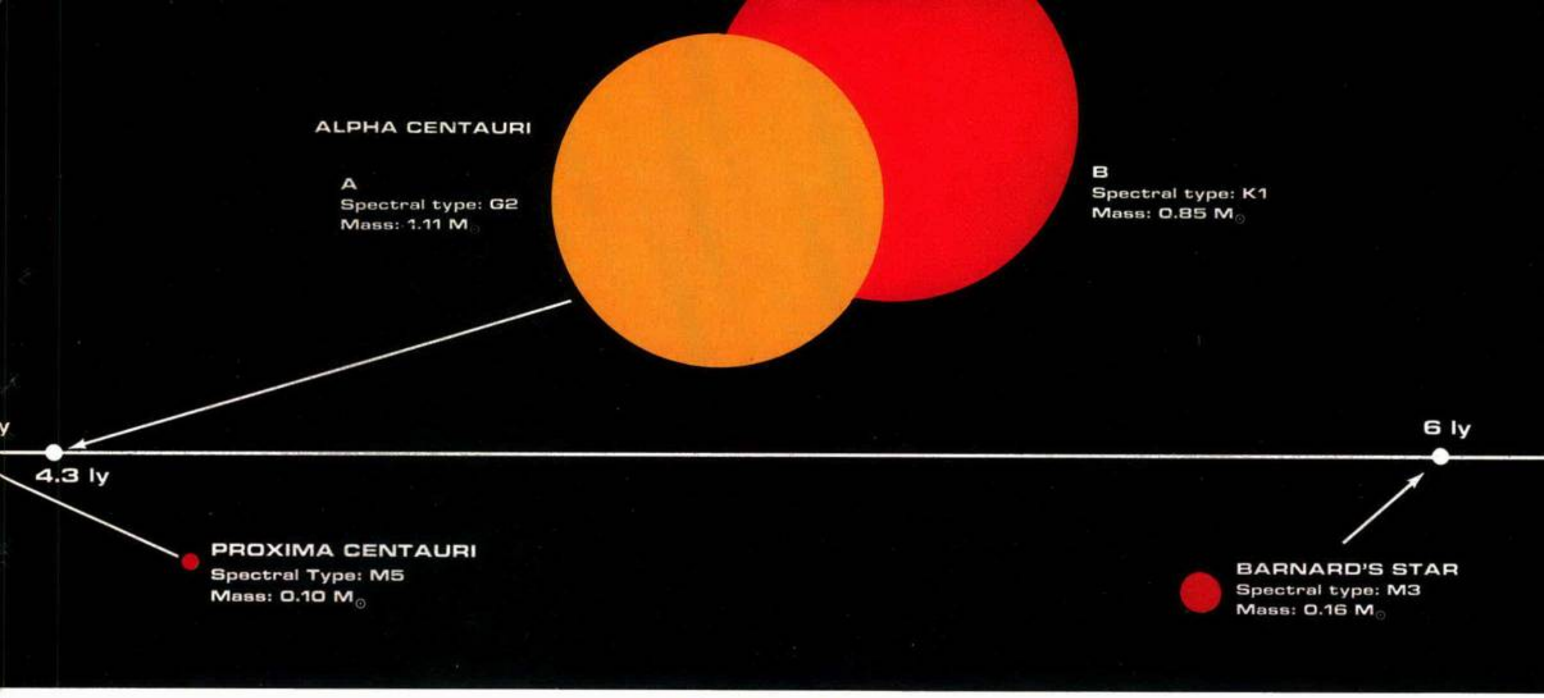
Our next star, Barnard's Star, lies 6.0 light-years from the Sun toward the constellation Ophiuchus. Although it is a red dwarf like Proxima Centauri, Barnard's star is an old star. It is one of the Sun's most interesting stellar neighbors because some astronomers think it is the home of a planetary system. The Dutch astronomer Peter van de Kamp claimed in 1962 that he had detected wobbles in the star's motion across the sky. He felt these wobbles were caused by gravitational tugs from orbiting planets. According to van de Kamp's latest analysis, made in 1982, Barnard's Star has at least two planets in nearly circular orbits. The largest, with a mass 70 percent that of Jupiter, revolves around the star every 12 years. Many astronomers disagree with this, but the evidence is suggestive enough for astronomers to keep close watch on the star's motion.

Continuing our tour, we leave Barnard's Star and its possible planets behind and journey to the faint red dwarf Wolf 359, 7.7 light-years from the Sun. With an absolute magnitude of only +16.65 this star probably has a mass close to 0.10 $M_\odot$ — tiny, even for a red dwarf. Like Proxima Centauri, Wolf 359 is a flare star. Beyond Wolf 359 lies Lalande 21185, another red dwarf, although it appears to be an old star.

Our next stop is the interesting binary Luyten 726-8 in the constellation Cetus. This system consists of two dim red dwarfs 8.4 light-years from the Sun. The fainter of the two, L 726-8 B, is also called UV Ceti and is one of the most famous red dwarf flare stars in the sky. Because the stars are in a binary system, we can use Kepler's Third Law to determine their masses. The brighter star has a mass of only 0.12 $M_\odot$ and the dimmer one 0.11 $M_\odot$.

After visiting these faint, low-mass stars, we come to a very different binary system. Lying 8.6 light-years from the Sun, the Sirius system contains the brightest star in the sky. Sirius A is a hot A-type star with an absolute magnitude of +1.42, making it the most luminous star on our journey. The main reason Sirius looks so bright in our sky is that it's so close to us. If a star like Orion's Rigel were at the distance of Sirius, it would outshine Sirius by more than a thousand times.

Orbiting Sirius A is Sirius B, a white dwarf star. Sirius B used up its fuel long ago and it is the first star we have encountered that is not a main-sequence star. Sirius B is hot and dense and, although nearly as massive as the Sun,



it is about the size of Earth.

Sirius A, however, has a mass of 2.2 $M_{\odot}$. It is more massive than Sirius B and should have "died" first, becoming a white dwarf before Sirius B did. But Sirius B was probably much more massive when is sparked to life than Sirius A. After it used up the fuel at its core, Sirius B expanded into a red giant and, because red giants lose a lot of mass, Sirius B probably lost most of its mass then. Moreover, some of this mass may have fallen on Sirius A, increasing that star's mass too. The Sirius system reminds us that stars do not always exist as independent individuals but may owe some of their unique characteristics to interactions with other stars.

Beyond Sirius lies Ross 154, 9.4 light-years away toward the constellation Sagittarius, and Ross 248, 10.4 light-years toward Andromeda. Both of these stars are red dwarfs, and Ross 154 is a flare star.

Next in our tour comes Epsilon Eridani, a star with a spectral type of K2 and an absolute magnitude of +6.14, lying 10.8 light-years from the Sun. Although it is cooler, fainter, and less massive than the Sun, Epsilon Eridani is more like the Sun than most nearby stars. Epsilon Eridani is also a single star, so it could harbor planets. The star has an active atmosphere, though, which suggests it is young — less than 1 billion years old. So even if planets exist around Epsilon Eridani, intelligent life probably has not had time yet to evolve on them.

The next star outward is Ross 128 in the constellation Virgo, which is yet another red dwarf star. It is a single star with no unusual characteristics. Beyond it lies the famous double star 61 Cygni, 11.1 light-years from the Sun. This star system is composed of two K-type stars, somewhat fainter and less massive than Epsilon Eridani, which orbit each other every 650 years. The brighter component has a spectral type of K5 and an absolute magnitude of +7.56.

61 Cygni is famous because the German astronomer Friedrich Bessel measured its parallax in 1838, making it the first star other than the Sun to have its distance determined. Even today parallax is still the most accurate way to determine a star's distance, though it only works for the nearest stars. To measure more distant stars astronomers must use less reliable methods.

Beyond the 61 Cygni star system lies the star Epsilon Indi, 11.2 light-years from the Sun. Its spectral type is K5 and its absolute magnitude is +7.00. This star is two times fainter than Epsilon Eridani and seven times fainter than the Sun. Like Epsilon Eridani, Epsilon Indi is single; unlike Epsilon Eridani, Epsilon Indi may be a rather old star — older than the Sun. If Epsilon Indi has a planetary system, and if a K5 star is not too cool to support life, then living beings may have arisen on one of its planets.

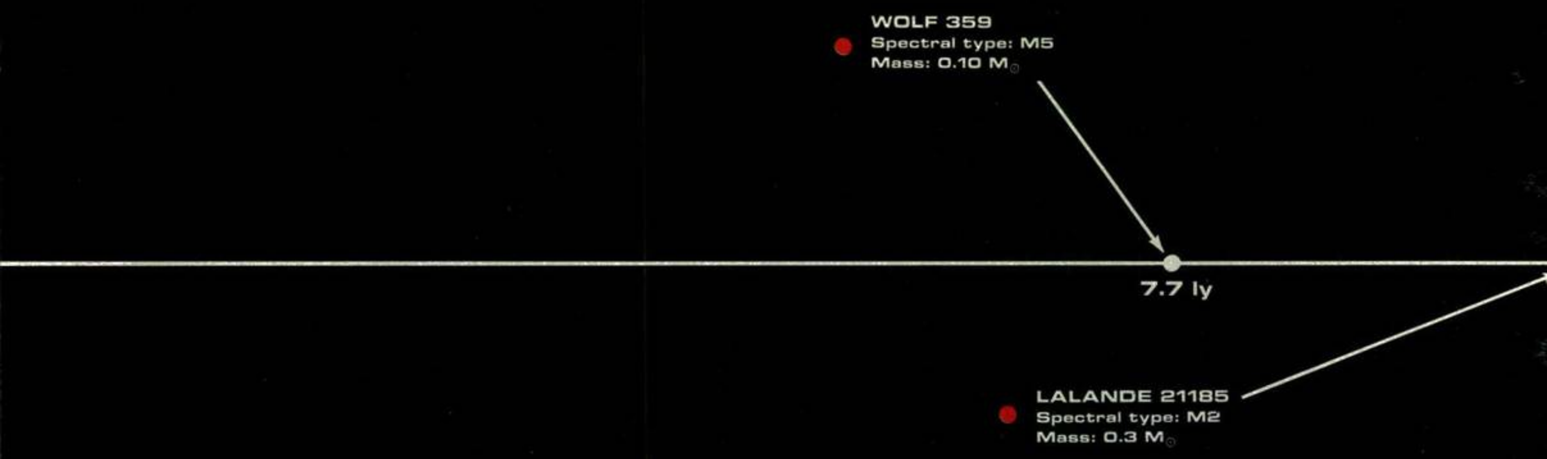
We next pass Luyten 789-6, a faint red dwarf lying 11.2 light-years from the Sun, and then the double star Groombridge 34, featuring two red dwarfs in orbit around each other.

Beyond Groombridge 34 lies the Procyon system, 11.4 light-years from the Sun. Procyon is one of the brightest stars in the night sky and, like Sirius, its fainter star is a white dwarf. The brighter component of this system, Procyon A, is an F-type star — the first F star we've met — that has begun to evolve off the main sequence. With a mass of 1.8 $M_{\odot}$, the star was probably an A-type star when it began its life. Also, Procyon is the third star we've encountered that is more luminous than the Sun.

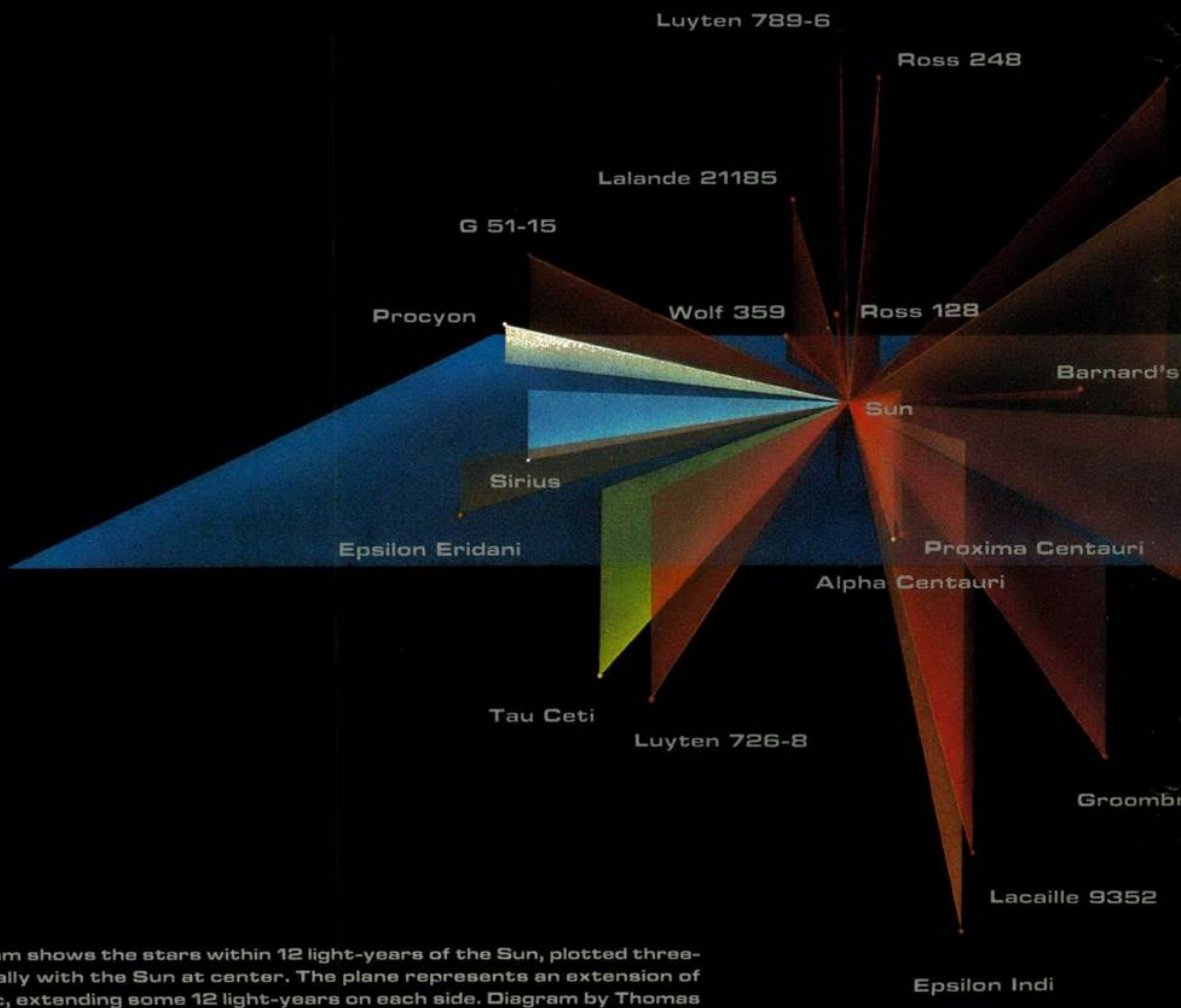
Our next three stops are systems containing red dwarfs. Struve 2398 is a binary that lies 11.6 light-years away and contains two red dwarfs. Beyond it lies Lacaille 9352. With an absolute magnitude of +9.58 it's the most luminous red dwarf on our itinerary, and has a mass of about 0.50 $M_{\odot}$.

The intrinsically faintest star on our journey is G 51-15 in Cancer. With an astonishingly dim absolute magnitude of +17.03, it is, in fact, one of the least luminous stars known. G 51-15 is so faint that astronomers did not even recognize it was a nearby star until 1972. This discovery may mean that there are other intrinsically faint stars closer to the Sun than currently thought.

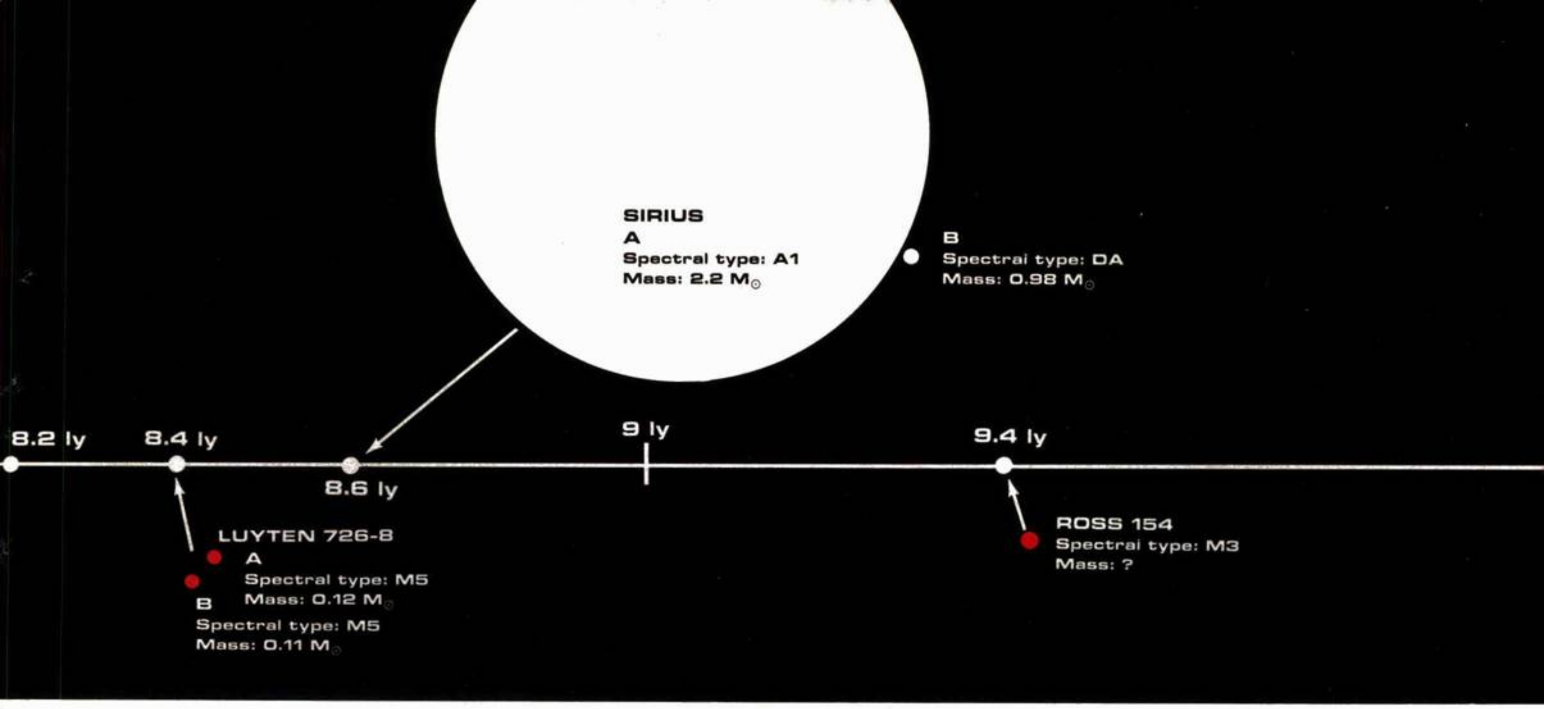
The final stop on our tour of nearby stars is Tau Ceti, 11.8 light-years from the Sun. Of all the star systems we have encountered, Tau Ceti is the one most like our Sun. Its spectral type is G8 and its absolute magnitude is +5.72. It is somewhat cooler than the Sun and only 45 percent as luminous. The star is single, so we cannot measure its mass directly but, given its spectral type, we can guess that its mass is about 0.9 $M_{\odot}$. Because Tau Ceti is a single,

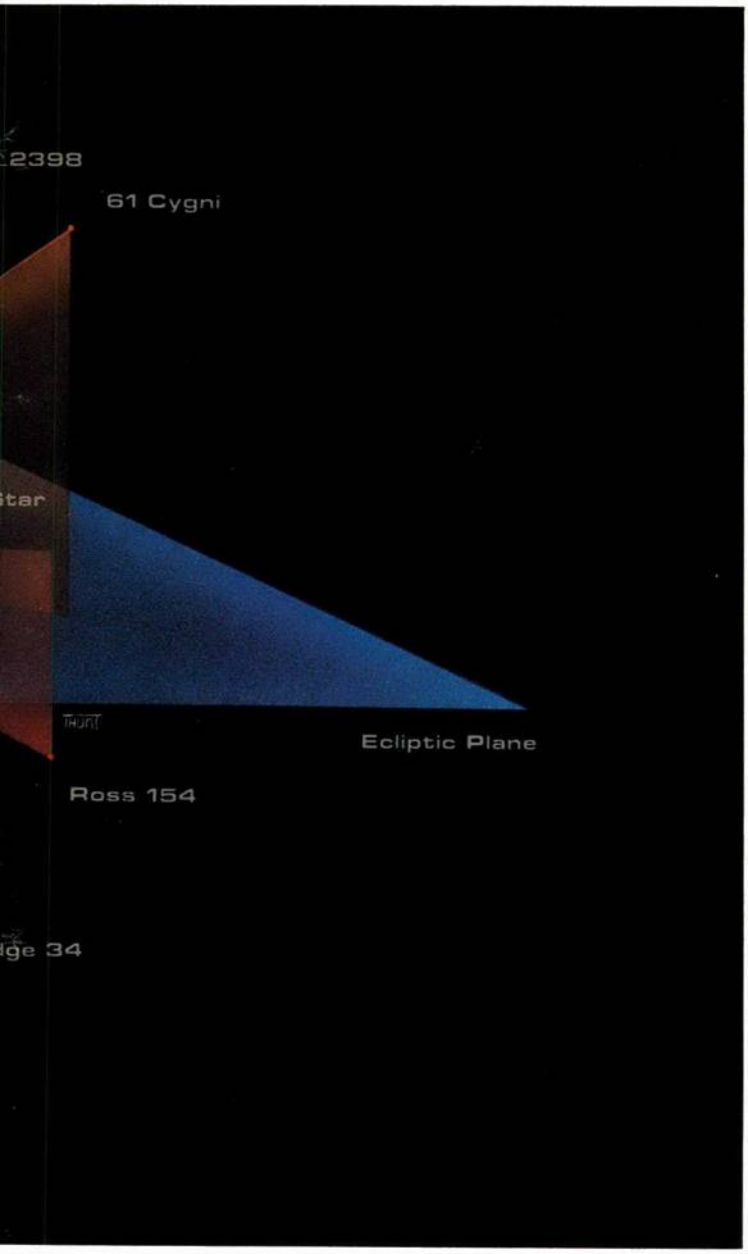

WOLF 359
Spectral type: M5
Mass: 0.10 $M_\odot$
7.7 ly
LALANDE 21185
Spectral type: M2
Mass: 0.3 $M_\odot$

The Solar Neighborhood in 3-D


Luyten 789-6
Ross 248
Lalande 21185
G 51-15
Procyon
Wolf 359
Ross 128
Barnard's
Sun
Sirius
Epsilon Eridani
Proxima Centauri
Alpha Centauri
Tau Ceti
Luyten 726-8
Groombr
Lacaille 9352
Epsilon Indi

This diagram shows the stars within 12 light-years of the Sun, plotted three-dimensionally with the Sun at center. The plane represents an extension of the ecliptic, extending some 12 light-years on each side. Diagram by Thomas L. Hunt.


SIRIUS
A
Spectral type: A1
Mass: 2.2 $M_{\odot}$
B
Spectral type: DA
Mass: 0.98 $M_{\odot}$
8.2 ly
8.4 ly
9 ly
9.4 ly
8.6 ly
LUYTEN 726-8
A
Spectral type: M5
Mass: 0.12 $M_{\odot}$
B
Spectral type: M5
Mass: 0.11 $M_{\odot}$
ROSS 154
Spectral type: M3
Mass: ?


2398
61 Cygni
tar
Ecliptic Plane
Ross 154
ge 34

G-type star, it may have planets. In fact, since Tau Ceti and Epsilon Eridani are so Sun-like, astronomers listened for radio signals from intelligent life emanating from them in 1960, but didn't detect any.

Analyzing the Sample

Now that we have completed our imaginary tour of the nearby stars, let's set a course back home. We've learned a good deal about the Sun's nearest neighbors and the stars we'll explore first when we launch an interstellar mission. But we've learned a lot more than that because stars that just happen to be near the Sun are a *random* sample of stars in the Galaxy. If we look back at what we've just seen, we can learn a good deal about how many stars of each different type exist in the Galaxy.

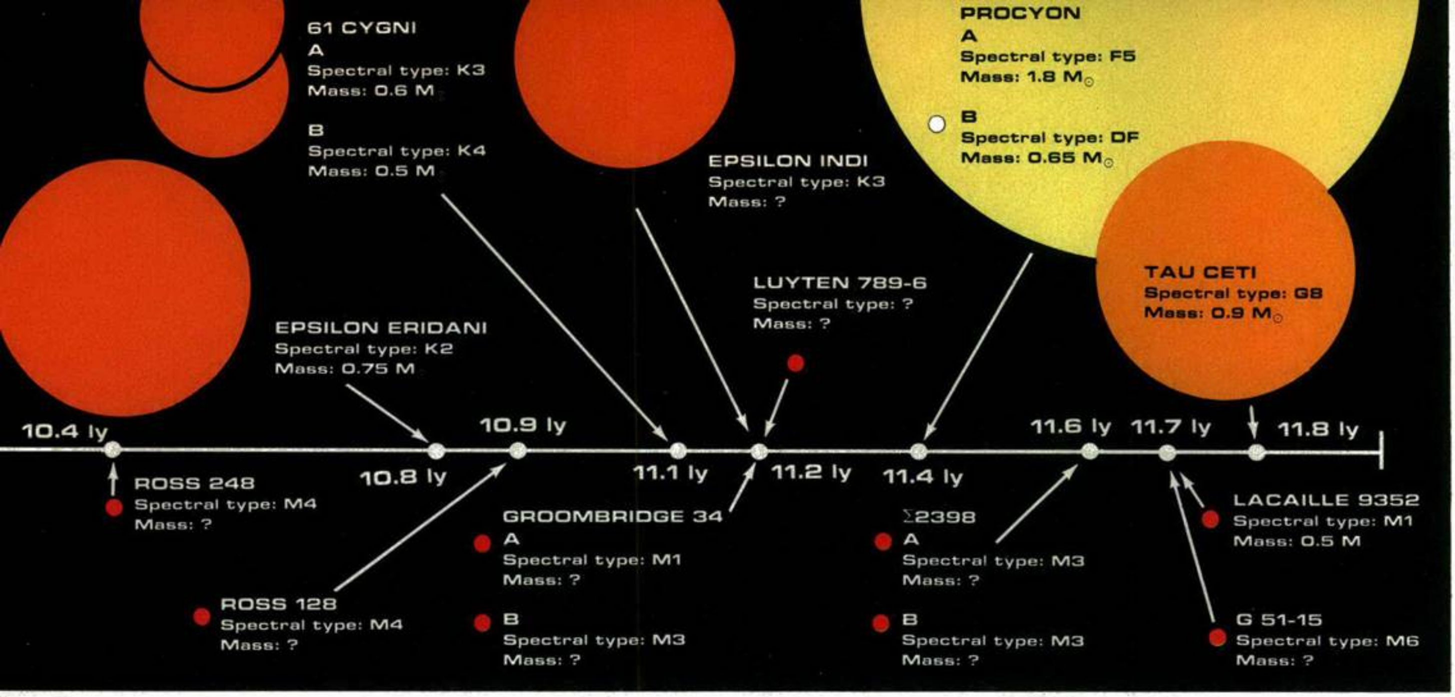
But before we do this, we must exclude the Sun from our sample. The Sun is *not* part of a random sample because it may be a special type of star: one that is circled by a life-supporting planet. Many astronomers believe intelligent life can evolve only around G-type stars because of their temperatures and chemical conditions. Our existence on one of the Sun's planets means the Sun must be a G star. If the Sun had been a short-lived B star or a faint red dwarf, humans probably would not have arisen to count any sample of stars. Stars *near* the Sun, on the other hand, are a random sample of stars from the galactic disk at the Sun's distance from the galactic center.

Our visit revealed nineteen star systems containing twenty-seven individual stars. Of these twenty-seven stars, fifteen — or 56 percent — were members of multiple-star systems. Also, twenty-five of the twenty-seven stars were on or near the main sequence. We encountered only two white dwarfs and no giant stars.

You probably noticed that a lot of the stars near us are red dwarfs, and that we met no O or B stars. Red dwarf stars must be very common then, and O and B stars must be very rare.

Here is the breakdown, by spectral type, of the twenty-five main-sequence stars we visited:

1 type A (4 percent of the total)
1 type F (4 percent)
2 type G (8 percent)
5 type K (20 percent)
16 type M (64 percent)


61 CYGNI
A
Spectral type: K3
Mass: 0.6 M
B
Spectral type: K4
Mass: 0.5 M
PROCYON
A
Spectral type: F5
Mass: 1.8 $M_\odot$
B
Spectral type: DF
Mass: 0.65 $M_\odot$
EPSILON INDI
Spectral type: K3
Mass: ?
TAU CETI
Spectral type: G8
Mass: 0.9 $M_\odot$
LUYTEN 789-6
Spectral type: ?
Mass: ?
EPSILON ERIDANI
Spectral type: K2
Mass: 0.75 M
10.4 ly
10.8 ly
10.9 ly
11.1 ly
11.2 ly
11.4 ly
11.6 ly
11.7 ly
11.8 ly
ROSS 248
Spectral type: M4
Mass: ?
ROSS 128
Spectral type: M4
Mass: ?
GROOMBRIDGE 34
A
Spectral type: M1
Mass: ?
B
Spectral type: M3
Mass: ?
Σ2398
A
Spectral type: M3
Mass: ?
B
Spectral type: M3
Mass: ?
LACAILLE 9352
Spectral type: M1
Mass: 0.5 M
G 51-15
Spectral type: M6
Mass: ?

In our sample the most common main-sequence stars we encountered were red dwarfs. Of the stars we surveyed, only three (Alpha Centauri A, Sirius A, and Procyon A) were intrinsically brighter than the Sun. So the Sun doesn't seem to be an average star at all — it is, instead, "way above average." According to this survey, it's in the top 14 percent of all stars in the Galaxy in luminosity and mass.

As any pollster knows, though, you can't draw conclusions from a sample this small. We can always improve our statistics by adding more stars to the survey and, with this in mind, astronomers have compiled catalogs of the nearest stars that extend much farther out than 12 light-years. The most famous of these catalogs is the *Gliese Catalog of Nearby Stars*. The German astronomer Wilhelm Gliese published the first edition in 1957; the second edition appeared in 1969. In 1979 he and Hartmut Jahreiss published a supplement to the second edition. Together the second edition and its supplement list all known stars within 72 light-years of the Sun. There are over 1,500 such star systems.

Still, more than half the stars within 72 light-years are probably missing from the catalog. Which stars are missing? Certainly not the bright A and F stars — we can see all of them. The intrinsically faint stars are hard to see, so the catalog discriminates against them. And scientists who forget about them can make some huge errors. Astronomers call an effect that biases a survey like this a selection effect.

To take an extreme example, suppose we tried to determine the average absolute magnitude of all stars by surveying the twenty brightest stars in the sky. We would find the average absolute magnitude is about −1, corresponding to a luminosity 200 times greater than the Sun's. Yet, from our tour of the nearby stars, we know this is totally wrong, because the average star is a red dwarf, and the typical stellar luminosity is hundreds of times *less* than the Sun's. Making this mistake is like trying to determine the average income of Americans by polling only those Americans who drive Cadillacs.

When confronted by a selection effect they cannot eliminate, astronomers generally try to do two things. First, they try to determine which way the selection effect biases the survey. Even though a survey of the nearest stars is much less biased than that of the brightest stars, it still discriminates against the intrinsically fainter stars. Second, they try to estimate the size of the bias.

Recall from our survey of stars within 12 light-years, that we placed our Sun in the top 14 percent of stars. When scientists allow for the existence of intrinsically fainter stars — red dwarfs and white dwarfs — they find that our Sun is in the top 4 percent of all stars. In other words, 96 percent of all stars are intrinsically fainter than the Sun, and nearly all of these are less massive than the Sun as well. (Some of these faint stars are white dwarfs, and a few of them are more massive than the Sun even though they're fainter.)

Now assume that there are stars even intrinsically fainter than red dwarfs and white dwarfs — brown dwarfs. Brown dwarfs range in mass from 0.01 $M_\odot$ to 0.085 $M_\odot$ and, although they are sometimes called "planets," they are *not* planets but stars too small to ignite their fuel. (See "Stars Too Small to Burn," ASTRONOMY, April 1984.) In the last three years astronomers have identified two brown dwarf candidates: LHS 2924 (28 light-years away) and VB 8 B (21 light-years away). Some scientists believe brown dwarfs may outnumber all other types of stars put together. If true, this would place the Sun in the top 1 or 2 percent of all stars in the Galaxy! Unfortunately, detecting brown dwarfs beyond a short distance in our part of the Milky Way would be exceedingly difficult.

Our tour of the nearby stars has revealed the enormous diversity of the stellar population near the Sun. Yet, as we return home from our imaginary voyage, we may also be filled with a renewed appreciation for the Sun. Most stars are fainter and less massive than the Sun, and most of these probably cannot support life. Tau Ceti and Epsilon Eridani may come close, but it may be tens of thousands of years before we know for certain whether the Galaxy is teeming with life, or that we are in cosmic isolation.

Ken Croswell is a graduate student at Harvard University. His last article for ASTRONOMY was "Pluto: Enigma on the Edge of the Solar System," which appeared in the July 1986 issue.

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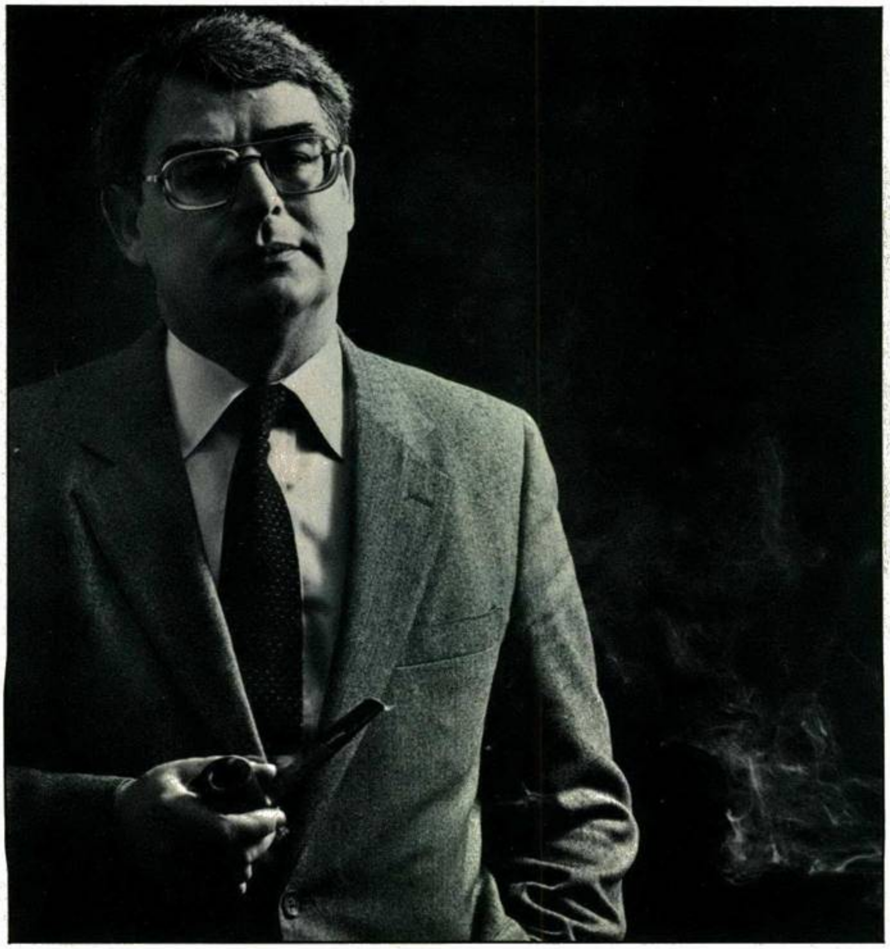
Continuing the Tradition: Amateur Astronomers and the Space Telescope

Riccardo Giacconi, director of the Space Telescope Science Institute in Baltimore, Maryland, announced the Institute's decision to reserve observing time on the Hubble Space Telescope for amateur astronomers at last summer's ASTROCON, the national convention of the Astronomical League held in Baltimore.

The following is the text of Giacconi's speech, which was given on August 7, 1986.

I am here today to announce a program whereby amateur astronomers will have observing time on NASA's Hubble Space Telescope. We expect that the Hubble Space Telescope, a project of international cooperation between NASA and the European Space Agency, will be the forefront instrument in optical and ultraviolet astronomy for the rest of this century.



As soon as the Space Shuttle returns to service, the Hubble Space Telescope promises to do what it can to accomplish [these objectives]: to be a permanent observatory above the murky, turbulent atmosphere of Earth; to see celestial objects fifty times too faint to be detected by groundbased telescopes; to improve angular resolution so that we see details and separations between objects ten times better than from Earth; to see not only in the optical wavelengths, but also in the ultraviolet and infrared — wavelengths which are absorbed in the Earth's atmosphere and are mostly unavailable for study from the ground.

Almost everywhere Space Telescope points, there is the likelihood of new discoveries. Naturally this powerful instrument is anxiously anticipated by professional astronomers. Observing time on Space Telescope will be at a premium. Out of an expected thousand applications a year, Space Telescope may be able to accommodate 10 or 20 percent.

An offer of Hubble Space Telescope observing time to amateur astronomers, therefore, is not lightly made. Yet I am making this offer to you today.

This I am able to do because NASA did something unprecedented when it inaugurated the Space Telescope project: it entrusted the telescope's scientific operation to the scientific community through the establishment of the Space Telescope Science Institute. One of the functions of the Institute is to assign observing time. We do this through the advice of peer review committees which examine observing proposals from astronomers worldwide and rank them on the basis of merit.

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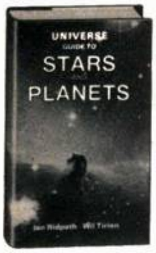
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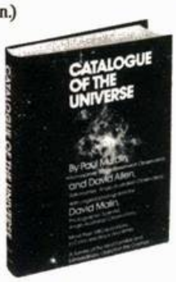
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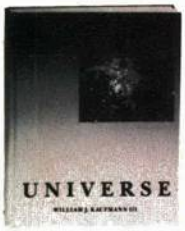
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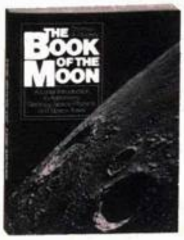
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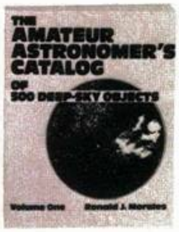
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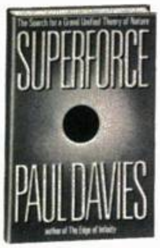
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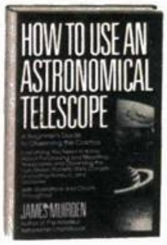
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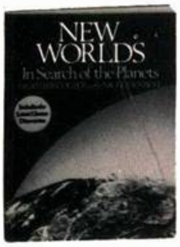
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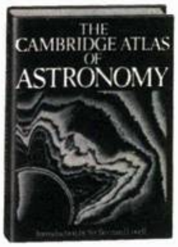
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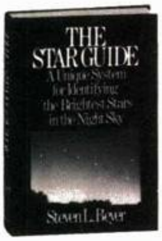
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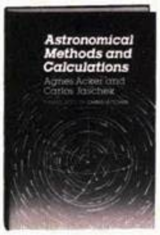
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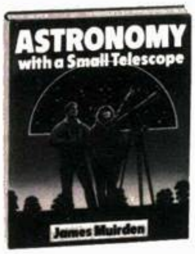
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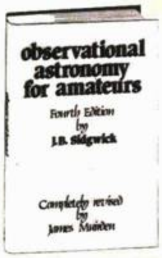
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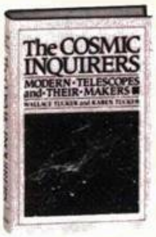
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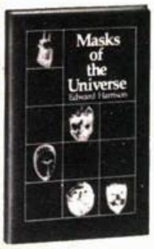
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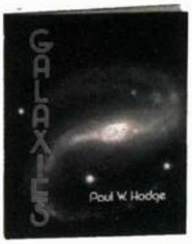
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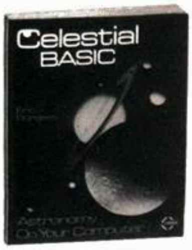
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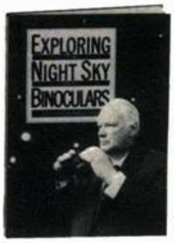
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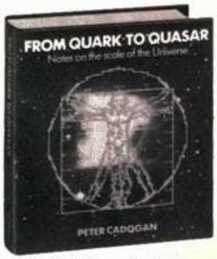
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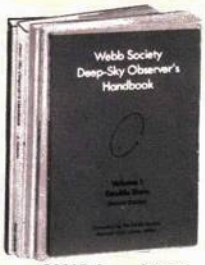
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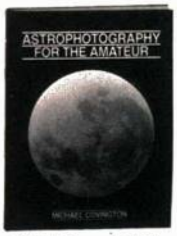
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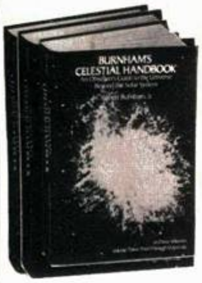
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If the reply card has been removed, please write to Astronomy Book Club, Dept. L-BT3, Riverside, N.J. 08075 to obtain membership information and an application. Astronomy 1/87 and the scientists have given me a small allotment of time to hold in reserve for projects of unusual promise and for special targets of opportunity. I am announcing today that I am reserving a few hours from the Director's Discretionary Time for use by amateur astronomers under an amateur astronomer peer review system worked out by your representatives.

Last December I invited to the Institute leaders from nationally and internationally known American amateur astronomer societies. I spoke to them about my hope that amateur astronomers could participate in the Hubble Space Telescope project in three ways: through collaborative efforts between Space Telescope observers and amateurs; through access to archival material; and, finally, through the direct assignment of observing time to amateurs. If they were interested, they could count on the support of the Space Telescope Science Institute, but we would need to rely on amateur astronomers and their organizations to create an approach and nurture it to fruition.

At that first meeting your representatives formed themselves into the Hubble Space Telescope Amateur Astronomers Working Group and presented me with an impressive plan to give you the opportunity that Congress, NASA, many scientists, and I thought you deserved. We each have done our part since then. The Institute staff has worked closely with NASA officials to set the general framework under which the program can be carried out.

Your representatives have worked hard over the past eight months to bring us to the point of this announcement today. The next year will be still harder for them as they work together with you to generate and review the proposals that will allow amateur astronomers to see the universe as no one has ever seen it before.

I realize that most of you know these dedicated leaders, but I would like to take a moment to recognize them and join you in thanking them for the job they are doing. From the American Association of Variable Star Observers, its director, Dr. Janet Mattei; Association of Lunar and Planetary Observers, Dr. John Westfall, Acting Director; Astronomical League, George Ellis, President; Independent Space Research Group, Jesse Eichenlaub, President; International Amateur-Professional Photoelectric Photometry, Gerry Persha, representative; International Occultation Timing Association, its president, Dr. David Dunham; and Western Amateur Astronomers, Steve Edberg, President. Mr. Edberg was elected this year's chairman of the Hubble Space Telescope Amateur Astronomers Working Group.

I also would like to recognize the efforts of Mark Littmann, Michael Potter, and Laura Fournier on the Space Telescope Science Institute staff who have worked hard to make all this happen.

You, as amateur astronomers, have your own special projects. But your work is well known to professional astronomers. We have long been dependent on you to be our eyes for long-term observations and our lookouts for sudden events. We have depended on you as well to explain astronomical research to the public at large.

In times past amateur astronomy provided many of the fundamental advances in astronomical knowledge. One has only to think of the contributions of the Herschels, of Schwabe, and many others in the eighteenth and nineteenth centuries to understand that amateur astronomy has played a central role in the advancement of the discipline. Even as recently as the early 1900s we find that the amateur had an important role to play in some of the major discoveries. One story is particularly apropos because of its connection to Edwin P. Hubble.

A young man from Dodge Center, Minnesota, dropped out of high school at age fourteen, went off alone to southern California, and found work as a mule driver carrying supplies to the astronomers atop Mount Wilson. After each grueling trip up the mountain, instead of sleeping at night before starting down, this young man would stay up with the astronomers talking about their projects. Eventually the astronomers began letting him take a few pictures and make a few measurements.

Roads and trucks soon replaced packtrains and the young man eventually became a ranch foreman. Yet the lure of the mountain was too great and in 1917 he returned to Mount Wilson — as a janitor.

The great new 100-inch telescope had just been installed. Excitement was high. This young man resumed hanging around the telescopes at night. More and more, astronomers trusted him to take a spectrogram or a photograph. He could get more from the equipment than they could. It was uncanny.

He did not last long as a janitor. Milton Humason became a night assistant and then a member of the scientific staff. His remarkable spectra of galaxies in his collaboration with Edwin P. Hubble resulted in the discovery of the expanding universe and the Hubble Law that relates the distance of a galaxy to its speed of recession. It was the greatest discovery in Hubble's distinguished career and is the reason that NASA's large orbiting telescope has been named the Hubble Space Telescope.

But Hubble's work on the expanding universe was a collaboration: Hubble, the Rhodes scholar, with Milton Humason, a high school dropout, former mule driver, amateur astronomer, and observational astronomer of the highest caliber.

Amateur astronomers' contributions to the progress of astronomy did not cease at the beginning of this century. Amateur organizations are more vibrant and alive today than any time in the past. Their accomplishments, their projects, and their help to professional astronomers are so extensive that I can mention only a few activities as representative of the talent and dedication here today:

- Amateur astronomers are mapping portions of the Moon not adequately covered by lunar probes and Apollo missions.
- Amateur astronomers calculate and observe when asteroids pass in front of distant stars. These occultations provide information about asteroid sizes and orbits.
- Amateur astronomers monitor special types of variable stars for flares and eruptions, crucial to an understanding of stellar evolution.
- Amateur astronomers are pioneering automated equipment to scan galaxies in search of exploding stars that give us information about stellar evolution and the distance to those galaxies.
- Amateur astronomers are working to design, build, and fly aboard the Space Shuttle an 18-inch Amateur Space Telescope.

These projects are just a few from the broad spectrum of amateur astronomer activities today.

The professional astronomical community knows of your work, and we are grateful. I need go no further than a few steps down the halls at the Space Telescope Science Institute to hear numerous stories from professional astronomers on the Institute staff that you have helped. Howard Bond and Sid Parsons are just two of the astronomers whose recent work was greatly aided by your efforts. Personally, as Principal Investigator for NASA's Einstein X-Ray Observatory, I was involved with — and impressed by — the collaborative efforts of amateur astronomers.

Amateur and professional astronomers share a great commonality of interests. We aid each other. You know this. So do I. Why then is there a feeling that a sharp separation now exists between amateur and professional astronomers? In the past the progress of astronomy was largely the

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work of amateurs. What has changed?

I was able to think of a few reasons: the general trend of industrial society toward specialization; the increased need for an arsenal of mathematical, theoretical, and physics tools to interpret the observational material, particularly after the early 1900s; and the increased size and cost of observing tools required for forefront research. Because these expensive facilities are few in number and mostly in private hands, there arose a certain exclusivity in their use.

All of these reasons have created barriers that are difficult to surmount. These barriers are most unfortunate. The dazzling discoveries by scientists remain curiously sterile unless they become assimilated in the general culture and become part of the intellectual heritage of mankind. Amateur astronomers have always been instrumental in providing that link and their impact on general education has been enormous.

Particularly today when new astronomical knowledge is accumulating at such a rapid rate, the connection between forefront research and education should be stronger than ever. Essentially all we know about the structure of the cosmos has been learned in this century. How old is the universe, how large, how will it end? How are stars born, how do they evolve, and how will they die? How were planets formed, how did they evolve, how did life arise? Are planetary systems, life, and intelligence abundant in the universe or are we alone? Such questions could not even be formulated at the beginning of this century; their answers seem now within grasp. I believe that ultimately the sociological impact of this new knowledge will be as great as the revolutions started by Copernicus, Galileo, Kepler, and Newton.

Let us reach out toward this new era together. The Hubble Space Telescope is almost ready. You shall have a chance to observe with it. I expect that amateur astronomers will use the Hubble Space Telescope to ask refreshingly new questions and that your findings will, as they always have, make a real contribution to the advancement of astronomy.

Rather than emphasize the differences between professionals and amateurs in a field such as astronomy where the distinctions are so thin, let us emphasize instead our common thirst for knowledge, our love of nature, and our appreciation of the beauty and mystery of the universe. And let us join our efforts to share these feelings with people everywhere. I hope today we are making a small step in that direction

—*Riccardo Giacconi*

First, Find Your Spider

While browsing through an antique shop, I discovered, nestled shyly among the jumbled bric-a-brac, a handsome brass filar micrometer, which is an eyepiece containing two delicate parallel crosshairs. One of the crosshairs is fixed, the other is adjusted by a calibrated external dial. It is used to accurately measure dimensions in a telescope's field of view, like the diameter of a planet or the separation between components of a binary star.

Apart from the dull hue of the oxidized brass, the only faults I could find were that the fixed "hair" was broken and that the movable filament was missing. No problem, I thought, these could be replaced. I snapped up the micrometer for a delightfully small sum.

The job of cleaning up the blackened brass took a tin of metal polish and some hard rubbing, and I soon had it gleaming like gold. I then had to decide on the material for the filaments. I remembered that the finest crosshairs are made from spider silk. Enthusiastic as ever I commenced my spider safari, and the most likely habitat seemed to be the garage.

On any normal day, this area is absolutely infested with creepy-crawlies of all kinds, especially spiders. Red ones, brown ones, big ones, and little ones. But word must have gotten around in the arthropod community that a big white hunter was at large. No matter how much I probed in dusty corners, in cracks and crevices, under piles of unsavory garbage, not a single spider could I find.

Just as I was about to give up, I discovered my quarry underneath an old can of paint. The luckless spider was scooped into a jar and carried ceremoniously to my bedroom desk, where the micrometer lay in pieces ready for the transfusion.

The creature was obviously very pleased with its newfound purpose in life. It scuttled around inside its prison with great speed and nimbleness. Since I now had my spider, only the simple task of extracting its web remained.

I had seen the technique demonstrated in an astronomy program on television. The spider is first persuaded to sit obediently on one branch of a two-pronged fork; it is then allowed to drop from the fork trailing a thread, which is wound up like spaghetti. I rigged up a crude fork with a pair of pencils and set about the task.

Clearly my captive did not watch TV. Have you ever tried to get a spider to climb onto a pencil? Eventually, by making it run about and jabbing the pencil suddenly into the path of its helter-skelter escape route, I got it to collide with my fork. Of course it did not stay there. It immediately headed up the pencil toward the hand that held it. So it was with some relief, and not a little panic, that I flicked the spider off into space.

Sure enough, there it hung — a diaphanous silken thread with an angry wriggling body on the end of it. Before it could climb back up its own safety line I carefully wound a single strand across the points of the fork and

Todd Graveline

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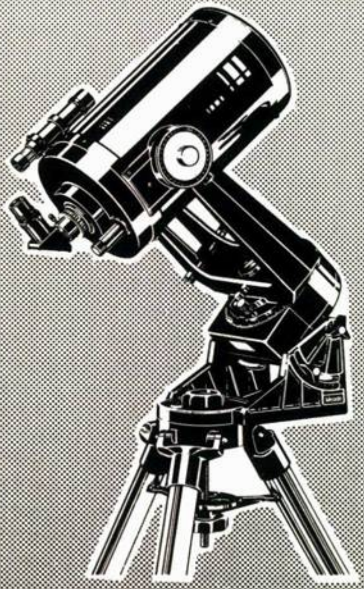

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dropped my little web factory back into the jar. Success! I had my first thread, and now only had to place it on the graticule frame to bring the operation to a happy conclusion.

The thread was so fine, however, that it was practically invisible. It could only be seen momentarily, if the light struck it from the right direction, thus making it impossible to maneuver into position accurately.

My first thread broke. So did my second, third, fourth, and fifth. I was losing my cool, as was the agonized spider. I definitely saw a look of increasing dismay and dread when I removed the lid of its prison for a sixth attempt.

I eventually arrived at the conclusion that the spider was too small and that I needed a larger one with more resilient thread. Besides, I must have exhausted its store of silk, since toward the end it kept falling off my special fork without a safety line. Back to the garage.

My second captive was twice as large and lively as his predecessor. This specimen proved to be an unworthy successor, however. It was obviously of a different species that did not use web material often. It stubbornly refused to produce any thread at all.

I returned to the dingy depths of the garage for my third spider, which turned out to be a friend of the second. It was clear that both belonged to the same militant wing of the Amalgamated Arthropod Silk Weavers Association, and were not going to produce one inch of web until we had agreed to terms. Again to the garage.

I was able to tease threads galore from spider number four's bulbous abdomen, but most were not strong enough to survive the transfer to the graticule. Those few that did, performed their natural function admirably by capturing airborne particles from nowhere — completely transforming a fine strand into a Christmas tree in less than a minute.

I decided I had suffered enough. I pulled my hair out! Well, not all of it, just two precious strands. I used these in place of a spider's thread, and they now repose inside my filar micrometer. A little too thick perhaps, but an easier solution than finding the right spider.

You may be wondering what happened to those reluctant creatures whose thread production was sought by a supposedly more intelligent being. You will be heartened to know that they performed one last service for me — as a welcome addition to the diet of my pet axolotl (a newt-like amphibian), which gulped these unexpected treats with great gusto.

Stephen D. Ringwood
Epping, Great Britain

The Universe from British Columbia

Living in Vancouver doesn't provide a lot of opportunities for serious observing, but fortunately dark skies and high altitudes are close enough so that I can occasionally indulge my lifelong fascination with astronomy.

This fascination began when I was much younger. Although I was a typical teenager, diving into something new almost every week, my interest in science never flagged. I joined the Royal Astronomical Society of Canada at the age of eleven.

In high school we did some fun things — one of the most memorable was taking a field trip to the Alouette tracking station. There was someone there who loved music and had actually made a tape with his own sliding scale of star magnitudes, spectral types, and radio frequencies all rolled up to give a particular musical note to a particular star. The music of the spheres indeed! I've loved astronomy ever since.

Alas, with the time I spent pursuing other goals, my 60mm refractor gathered dust. But still I kept an interest. I bought astronomy magazines, read everything on the subject in the newspapers, even devoured the astronomy section of my local library. An extended stay in the Middle East and India gave me the chance to visit ancient astronomical sites. Sleeping (ha!) in the open on an Afghani rug in the desert watching billions and billions of stars . . .

Later, there was *Burnham's Celestial Handbook*. Still, my observing was limited to using binoculars and public observatories. There were so many distractions in life. But I kept on talking about getting a *real* telescope. Closer and closer came the day, as the piles of brochures and advertisements built up like alluvial sediment. Enough already — *now* is the time. And there was light.

I got one of those 8-inch SCTs on a German equatorial mount. Fortunately I felt fairly familiar with right ascension and declination, so it wasn't difficult to get the hang of pointing the telescope in the general area. Polar alignment? Well, that took a while. But what really helped was our local chapter of the Royal Astronomical Society of Canada. What a great bunch of people!

Up we go to our local mountains every Friday and Saturday when it's clear and moonless. Sometimes it gets quite crowded (relatively speaking) up there. A collection of 8-inch scopes, one 10-inch, one 12-inch, and one 16-inch telescope complement the observers. Over 250 people were there for the Perseid meteor shower in August 1985, although the regular group consists of about ten people.

But none of this can compare to the 1985 Mount Kobau Star Party — five days of observing, camaraderie, and talks by professional and amateur astronomers at a site 6,100 feet above sea level in the interior of British Columbia. What a treat! Originally the site for the proposed 4-meter Queen Elizabeth Telescope, it is now empty except for a microwave repeater station and a fire lookout tower. Situated in one of the driest regions of the province, it is close to being a desert. And the sky is fantastic! In Vancouver we just don't see much of Sagittarius at all, not only because of our latitude, but because of light pollution from the city.

The weather looked good as we began our trip in Vancouver, but as we ascended the mountain the clouds began to pile up and up. Being disgustingly decadent, my girlfriend and I had rented a mobile home with another couple. Greg brought his two telescopes, I brought mine, and my girlfriend, Share, had her 60mm scope.

So there we were, waiting. Clouds. Oh well. We had a late supper and met some of the people already there. We looked at a very nice 20-inch Cassegrain, 16-inch Newtonians, and 17.5-inch Dobsonians. We were ready, but the sky wasn't.

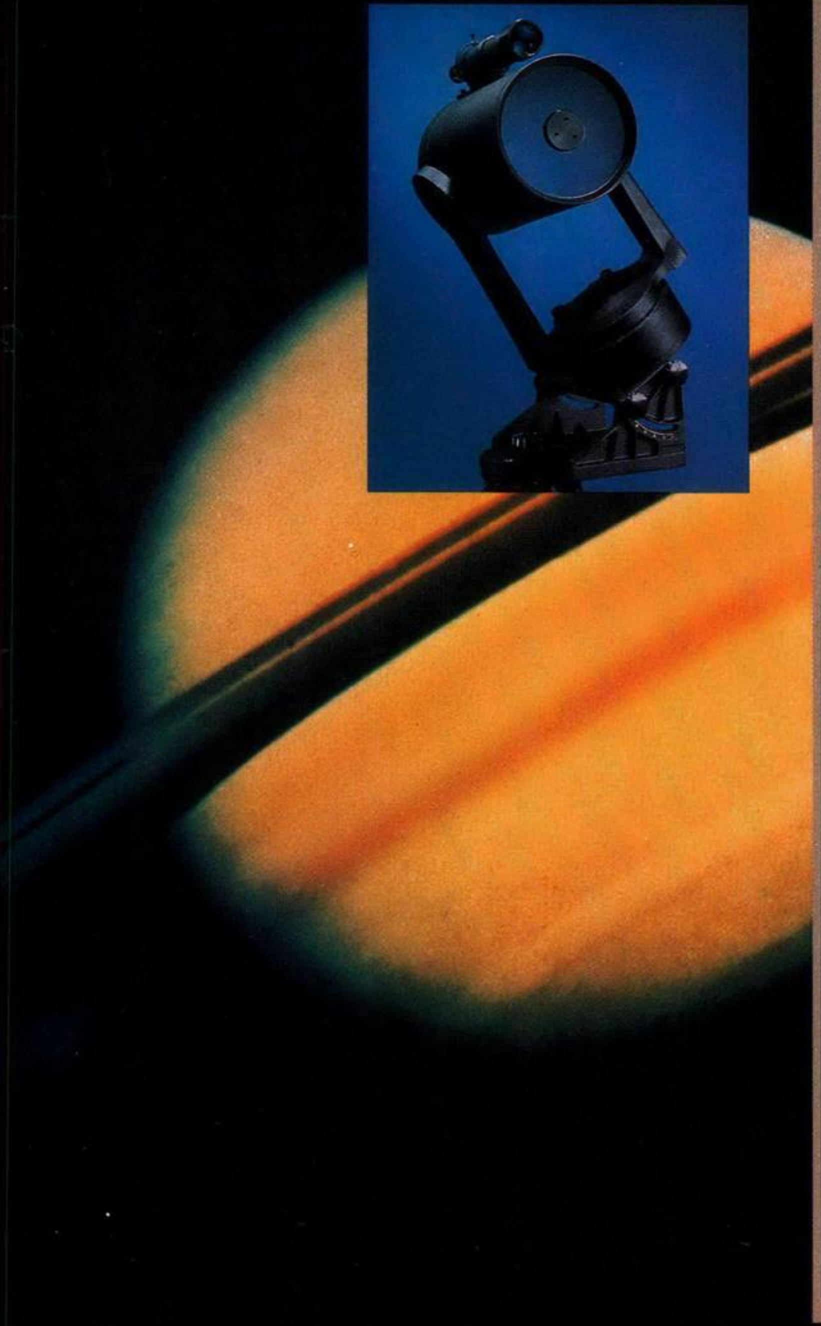
There was still no break by 11 p.m., so we crawled into our comfy beds. The folks in the tent next door must have been envious of our mobile home. You could almost hear them thinking: "Shameful. They call themselves astronomers? Hah! They have to be tough and freeze." It actually got damn cold, but we finally managed to fall asleep.

"It's clear!" someone shouted.

Our eyes popped open. It was 1:05 a.m. We cranked open the window on the roof above our noses. "Stars!" A raving lunatic wailed and danced around in glee out in the dark. I don't think I have ever unpacked and set up the scope as fast. Woolen hat and boots and gloves — brrrrr, it was cold outside.

Oh, my God! I thought. There it is — the Milky Way stretching from horizon to horizon. We are so high up in an unpopulated area that there are stars, clear as diamonds, *right to the horizon*. The constellations seem lost in the multitude of stars.

I looked up and shook my head. Is that—? I averted my eyes. There it is, the North America Nebula! Can it really be? I asked Greg, a much more experienced observer, "Do you see what I see?" Yup. We all felt so rested from the few hours sleep that the remainder of the night was spent



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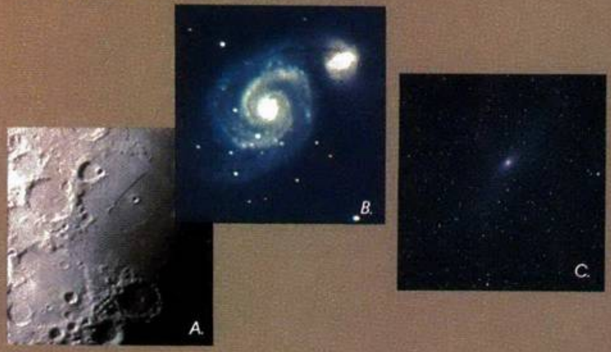

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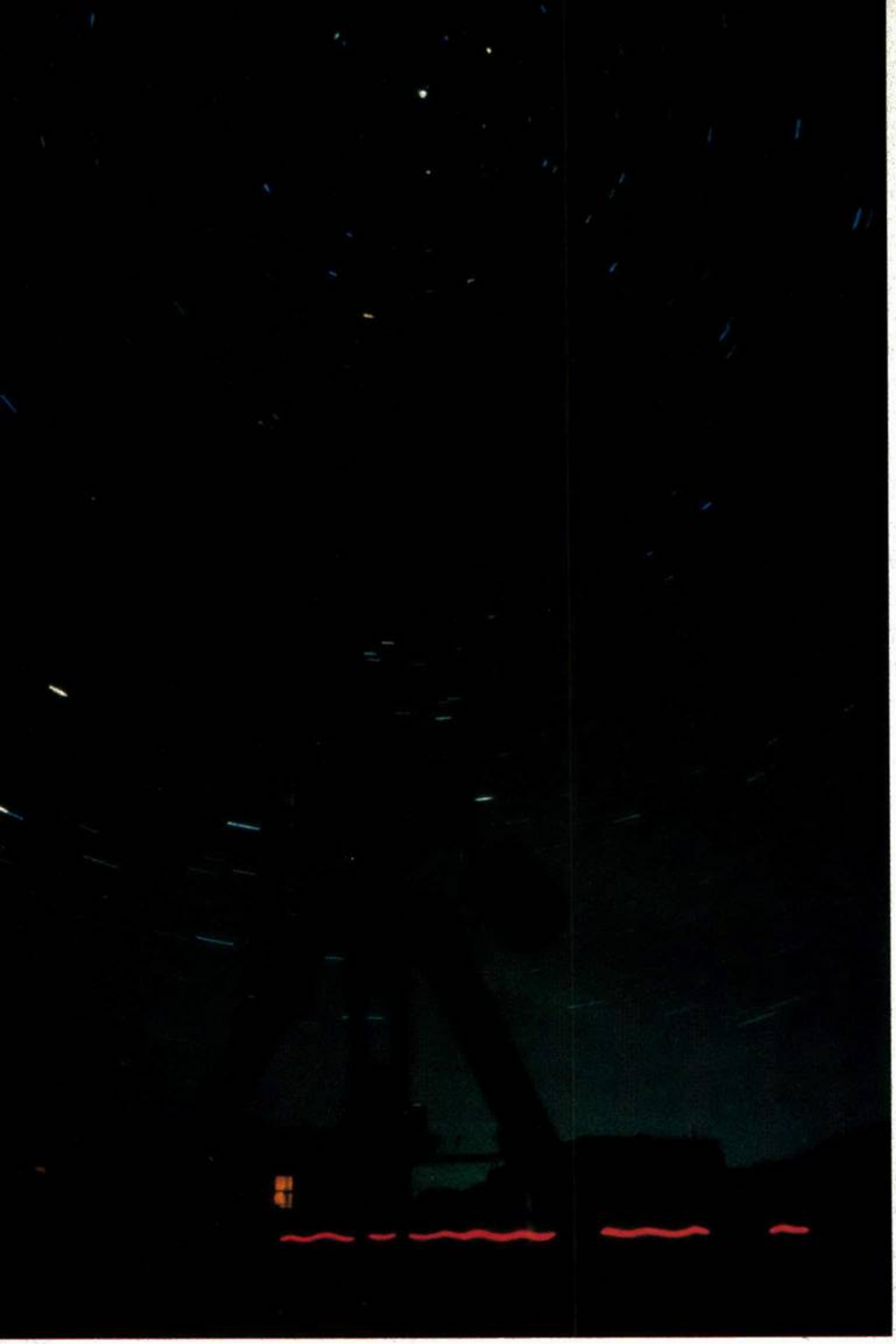

G. C. Knight

ooohing and ahhhing, dashing from scope to scope.

It was almost too much. Nobody had a planned schedule. It was so clear you could see the Arabian eyes behind the Veil. M-13, slipping off to the west, was a searchlight with buzzing bright moths circling. There was no problem picking it out with the naked eye.

At dawn we looked like a bunch of grinning idiots. There wasn't a cloud in sight. We slept for a few hours, then got up to walk around and see the place in daylight for the first time. We walked half a mile along the ridge to the fire station. What a view!

Early evening brought a talk and slide show on supernova remnants by Lloyd Higgs, director of the nearby Dominion Radio Astrophysical Observatory. More people arrived, and telescopes sprouted like mushrooms after a rain. The latecomers had to spread out farther and farther, but even so they had excellent sites with good clear views to the south.

It was dark and clear again that night. I must admit that I spent a bit less time at my own 8-inch telescope and much more at the 17.5- and 20-inch ones. M-51 was almost a religious experience. Later in the early morning the big scopes were almost exclusively hunting for Halley. No one was 100 percent sure he had found the comet because the field was full of 13th-magnitude stars. As the night wore on and I checked out an amazingly bright M-1, I kept an eye on the far eastern ridge. The Belt of Orion popped up, sharp and clear, right at the horizon. I'm waiting, antsy even.

"Oh, Share! Come look at this!" Through my telescope I could see the wispy tendrils of M-42 rising just above a group of trees. I don't think I'll ever forget it. In the brochure handed out at registration it was suggested that M-42 would be a fantastic way to end the night. I couldn't agree more.

We only left the mountain once in five days. In the valley, in the city of Osoyoos, it was 32°C, and all I wanted to do was get out of there. Back on top of the mountain it ranged from 14°C to 19°C, much better.

There were more talks that night. Joel Harris from the Jet Propulsion Laboratory gave a talk on Project Galileo and Craig McCaw spoke on astrophotography and cold cameras. Then came more observing. With a total ban on all white light past twilight, once you get your night vision, you keep it. M-33 with the unaided eye and the zodiacal light were just two of the extraordinary sights.

I created quite a stir when at 10:46 UT August 18 I saw a −2-magnitude flash just below Theta (θ) Arietis. "The Flasher," I cried. Another person just saw the wink. It was brilliant, built fast, lasted for approximately one second, and left no trail. My eyes jumped to Jupiter (setting), then Venus (rising), and Vega (also setting), trying to compare magnitudes. I thought it was the Ogre, but back home I checked out the latest news and photo of it and realized there was no way. It was almost 10° away from the now accepted location.

It must have been a brilliant point source meteor. There were some other bright meteors during our time there; one in particular was so bright that it left a trail you could still see in binoculars almost a minute after the flash.

Sorry I've gushed a little about this experience, but for someone who has basically been an armchair astronomer and has finally gotten out and observed, this star party has affected me deeply. To be with friendly and helpful people at a wonderful site with I-don't-know-how-many telescopes — well, it was a thrill.

I am actually *doing* it now, not just reading about it anymore. There were 70 people the first year at Mount Kobau, about 120 this year, and next year . . . well, I'll by there.

G. C. Knight
Vancouver, British Columbia

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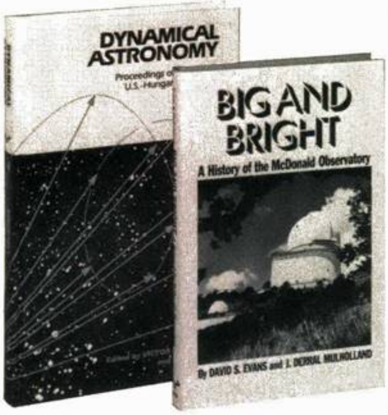
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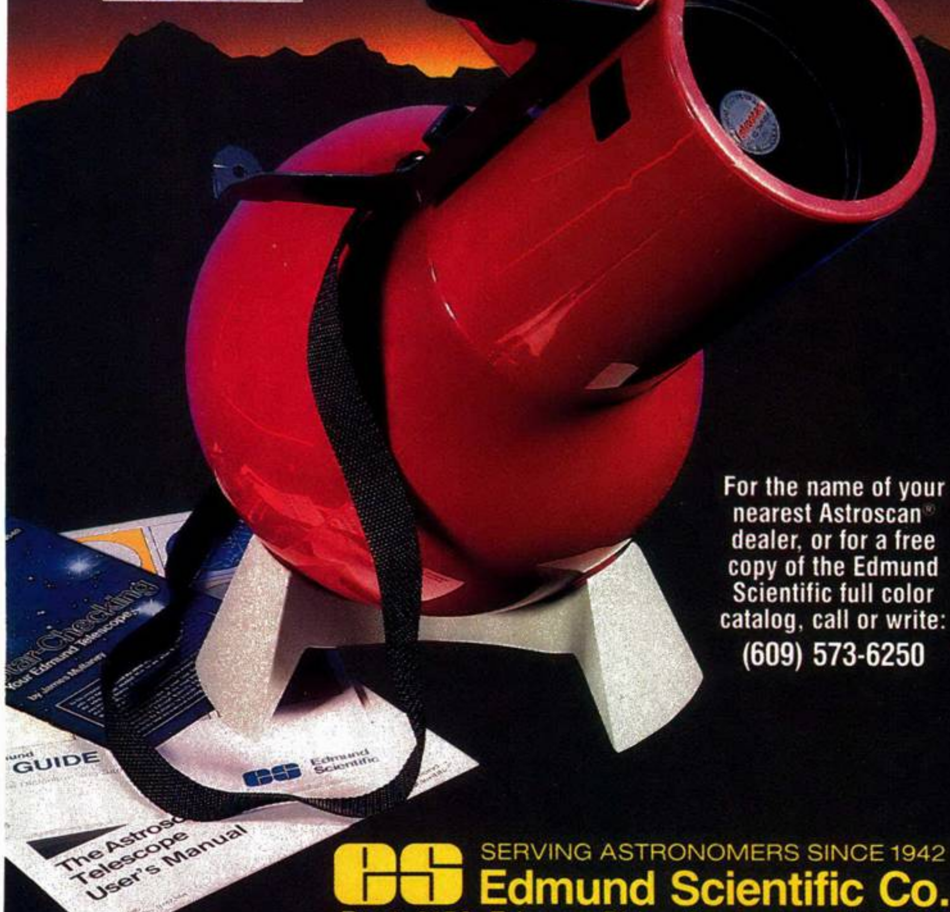

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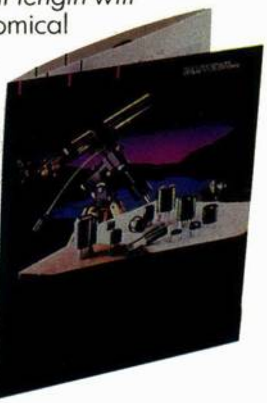

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ASTRONOMY
In Focus

Remembering Darker Skies

Sir / The interesting letters from Jo Parke in England and Paul J. Heafner in Santa Cruz, California (In Focus, September 1986) recall a time during World War II, in Europe at least, when light pollution was minimal. There was of course some interference with night vision over the target caused by bursting bombs, brilliant white incendiaries, searchlights, and bursting anti-aircraft shells, but otherwise the aircrew could see and admire the glowing heavens. See and admire but unfortunately not study, as survival depended to a great extent upon eternal vigiliance.

But these days, when squirting along in these modern tubes, only the driver and his mate can see the glory of the night sky.

The following poem, called "Two Worlds," was written in England in September 1944.

There's but One World, great Wilkie said
But men who fly know that instead
There are two worlds as far apart
As aeons hence from Nature's start.
The world below where mortal man
Does creep through his allotted span,
Where seldom can the Sun's clear ray
Break through to cheer his dismal day
And only stars that twinkle bright
Can watch his slumbers in the night.
But high above, another world
Before the sight does lie unfurled,
Where crystal air and bright blue sky
Does greet and stretch the viewing eye,
Where clouds are clean and brilliant white
And countless myriad stars at night
Do bring the Heavens nearer man
And show him Nature's master plan.

N. D. Greenaway
Warkworth, New Zealand

Telescope Advice from Your Local Planetarium

Sir / I read with interest "The 1986 ASTRONOMY Guide to Telescopes" (Equipment Atlas, October 1986). While I agree that most people do not have a "friendly local telescope store," most people often don't realize that they may have a "friendly local telescope advisor" at the nearest planetarium.

Planetaria are located in many cities across the United States. The people who work at these facilities can usually help the buyer make an informed decision. All he has to do is ask!

In addition to regular astronomy programs, many planetaria sponsor astronomy workshops, star parties, and classes about buying and using telescopes or binoculars. Some planetaria have associated observatories and conduct public telescope nights or provide meeting rooms for local astronomy clubs.

A prospective telescope buyer might try getting in touch with the staff at a nearby planetarium — that's one of the reasons we're here!

Dave Hostetter
Curator, Lafayette Planetarium
Lafayette, LA

Solar Filter Safety

Sir / Mr. Norm Peterson intended to be helpful in his letter (In Focus, October 1986), but he inadvertently gave the impression that metal-coated mylar filters are not safe for visual solar work. This is just not true. Dr. B. Ralph Chou of the School of Optometry of the University of Waterloo, Ontario, Canada, made a study of solar filters and reported the results in the *American Journal of Optometry and Physiological Optics* (July 1981). He stated unequivocally that properly made metal-coated mylar filters were safe.

Thin metal films have a very important characteristic: whatever their density, they always block *more* infrared than visible light. A metal film of sufficient density to make the image of the Sun comfortable to view is always dense enough to provide protection to the eye as far as the infrared rays are concerned. A neutral density 5 filter, which attenuates visible light by a factor of 10^5, or 100,000 times, reduces the brightness of the solar disk to that of the Full Moon.

Many other types of filters, including most sunglasses, smoked glass, and color transparency films, block the visible rays but not the dangerous infrared rays. When visible light is blocked, the pupil of the eye stays open, admitting large amounts of infrared. Such filters are not safe and should not be used.

The key to safety in solar filters is the filter material itself, which *must* be metal, regardless of the substrate. If the substrate is glass it can crack; if it is mylar it may have a hole. Of course, any filter with a defect in the coating or the substrate should be discarded.

Mark Replica
Elizabeth, NJ

— While Norm Peterson is possibly being overcautious, his caution is justified. Without access to a scanning spectrophotometer capable of covering the entire range of wavelengths transmitted by the atmosphere, it is difficult to determine whether a given filter is safe or not.

Although metal filters reflect more infrared than visible, they may transmit more in the ultraviolet than in the visible unless specifically made for, or tested for, suitability as solar filters. Although most glass optical elements absorb short-wave ultraviolet, some transmit significantly in the near-ultraviolet, so you shouldn't trust the *telescope's optical system to block what a filter should but doesn't. In short, don't trust a filter simply because it is shiny.*

Numerous firms sell metalized solar filters. These are listed in our "1986 ASTRONOMY Guide to Telescopes" and the "ASTRONOMY Equipment Directory" in the October issue. Dr. Chou tested solar filter products sold by several of these firms and found them to be safe.

If you are still nervous about direct solar viewing with a filter, remember that you can always view the Sun by projection.

Memorable Halley Photo

Sir / I credit my recent renewed interest in astronomy to Comet Halley and ASTRONOMY magazine. Your photo on page 44 of the June 1986 issue so clearly reminded me of my own view of the comet on a cold March morning in lower New York state some sixty miles from New York City.

Imagine my surprise when I saw your March 20 view of the comet on page 42 of the September 1986 issue. Something was wrong. The tail seemed to be oriented about right (although slightly steep), and the Trifid and Lagoon nebulae were properly at the upper right of the comet, just as I remembered. But where did the Teapot handle go?

This one baffled me until I realized that the photo must have been flipped when printed. The Teapot is there — it's just backwards. The comet tail still points to Nunki in Sagittarius no matter how the photo is printed.

Thanks for including this and the other photos of a once-in-a-lifetime memory.

Lowell C. Thelin
Clifton, NJ

— *In magazine jargon, the photograph was inadvertently flopped by the filmhouse, which is like looking at a slide from the wrong side.*

Help for Copyscope Builders

Sir / Any of your readers building a copyscope as described in "Building a Copyscope" (Equipment Atlas, May 1986) may want to obtain a helpful four-page leaflet called "Copier Lenses into Telescopes" by Dr. Wayne Wooten.

Several helpful pointers found in this leaflet include building a secure cradle for mounting your copyscope on a tripod, (the cradle base could easily be extended sideways to provide room for mounting a finder scope in tandem), and assembling your own star diagonal, Barlow lens, and extra eyepieces from good-quality surplus components.

To get a copy of the leaflet, write to Escambia Amateur Astronomers' Association, 6235 Omie Circle, Pensacola, FL 32504-7625. Enclose a self-addressed, stamped envelope.

Beginners and amateurs on a budget should also ask for the E.A.A.A.'s update on fine surplus eyepieces and ask to be put on the mailing list for the upcoming "New Horizons" newsletter, which will feature articles devoted to copier lens scopes.

J. R.
Ventura, CA

Tracking Down *The Night Sky*

Sir / In Robert Burnham's review of *The Night Sky* (Astronomy Reviews, September 1986), the publisher is listed as Collins. I have tried to locate this book in my local bookstore, but no one seems to be able to find it under that publisher. Can you help?

Elizabeth Earnshaw
La Grange, IL

— The Night Sky *by Ian Ridpath is published by Collins in England. In the United States it is distributed by Prentice-Hall, Inc., a division of Simon and Schuster. Its ISBN number is 0-671-62273-0.*

Oops!

In the November 1986 article titled "On Course for Neptune," the sentence discussing Voyager's polar-crown approach to Neptune should have read: "However, it is more likely that the main objective will remain the polar crown option, adjusting the nominal Triton flyby distance outward to perhaps *30,000* kilometers, if necessary, to maintain safe passages by the upper atmosphere *and the ring arcs.*"

Behind the Scenes

The Coldest Time of Year

Here in Wisconsin winter isn't very nice. The temperature often drops to 0° Fahrenheit; sometimes it gets even colder. We had several days of −25° weather a couple years ago. Pipes froze. Cars wouldn't start. Eyepieces frosted over. But we persevered.

Not that I'm bragging. I'd be happy living in a warmer place. And I know, too, that there are plenty of places where the mercury falls even lower. Minnesota, Alaska, Quebec, Labrador, Antarctica, Siberia. Hardy souls living in those places probably call out the Little League to play ball any time the temperature exceeds 0°.

But amateur astronomy goes forward even under wintertime conditions.

After reading Philip Bagnall's article on the prospects for the Quadrantid meteor shower this year, how many Wisconsinites will brave the cold? Consider how crisp and clear the skies are on those sub-zero nights. I'll bet there'll be more out than you'd think. How many Californians?

A boon for us frigid-climate types is the elimination of reciprocity failure in our film. Back in the olden days, before anyone knew much about gas hypering films, astrophotographers chilled their film well below the freezing point. Cooling inhibited the decay of the latent image, cutting reciprocity failure. So don't wait until next summer to follow Jim Baumgardt's tips on astrophotography without a telescope. Winter does have its advantages.

If you're still faint of heart (or chill of foot) about January observing, read the speech by Riccardo Giacconi in this month's Forum. He's giving amateur astronomers some time on the Hubble Space Telescope. When a guy like that lets you know *he* thinks you're hot stuff, how can you cower inside waiting for warm weather?

But if you are stuck inside this winter, why not use the time to build a 10-inch Dobsonian telescope, as Edgar Doleman suggests in Equipment Atlas. Cloudy winter nights are great for building, and in the spring you may find yourself out under the stars gazing at galaxies in the Virgo Cluster.

Of course, if you live in Florida, Alabama, Texas, Arizona, southern California, or one of those other places where it never gets cold — at least, not by Wisconsin standards — there's no excuse. We expect you out every clear night.

Sincerely,

Richard Berry

Richard Berry
Editor-in-Chief

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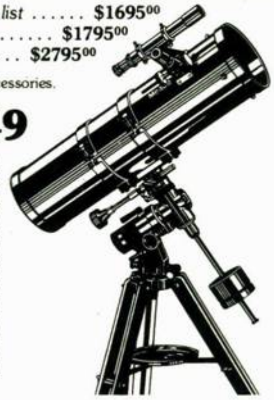

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Meade DS-10 10" f/4.5 reflector, pedestal mount, 25mm eyepiece, *$1400.00 list*	**$899.00**
Meade DS-10A, as above, but with setting circles and AC worm drive, *$1600.00 list*	**$999.00**
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The Quadrantids: Bright Prospects for 1987

Gazer's Gazette

by Philip M. Bagnall

The dawn of a new year frequently brings a severe case of the doldrums — the holidays are over, the weather is often lousy, and spring seems an eternity away. Not even amateur astronomers are immune to this malady. But if you're willing to brave the cold night air this month you might find a cure in a sky full of bright meteors, for the advent of 1987 brings with it the prospect of a brilliant display from the Quadrantid meteor shower.

The Quadrantids are currently one of the most active meteor showers of the year — comparable only to the Perseids — but they are also one of the most difficult to observe. There are several reasons for this. Inclement weather is, of course, a principal factor, yet even when the sky is clear and the weather calm the cards are definitely stacked against observers.

In mid-northern latitudes the radiant does not reach a reasonable altitude until 2 a.m. local time, leaving only five hours of observing before dawn. In addition, the period of maximum activity is short. Although the Zenithal Hourly Rate (ZHR) reaches a peak of around eighty meteors per hour, the rate exceeds twenty for just sixteen hours (compared to over one hundred hours for the Perseid meteor shower).

If that isn't enough, observing the Quadrantids is hampered one out of every three years by moonlight. So to catch the shower at its best, part of the sixteen-hour peak period must fall between 2 a.m. and 7 a.m., when the Moon is within a few days either side of new and the weather is favorable!

It is hardly surprising, then, that few observers have seen the Quadrantids. Yet those who have find it to be both exciting and intriguing, and well worth the effort.

An Orphan Stream

Meteor showers are born from dust-laden comets that approach the Sun and begin to disintegrate. The particles ejected from the cometary nucleus generally remain in this same orbit, forming what is known as a meteor stream. It is not unusual, therefore, to find streams and comets in similar orbits. The Perseids, for example, are associated with Comet Swift-Tuttle (1862 III) (see "Comet Swift-Tuttle and the Perseids," ASTRONOMY, August 1983) and the April Lyrids with Comet Thatcher (1861 I). Despite many careful searches, however, a comet with an orbit similar to the Quadrantid meteor stream has never been found — it appears to have lost its parent. In recent years many astronomers have asked if we are even looking for the right object.

The Geminids, which are active during early to mid-December, were likewise considered orphans until a few years ago. Then, in 1983, the Infrared Astronomy Satellite discovered an *asteroid* in an orbit almost identical to the Geminid stream. Now named 3200 Phaeton, this minor planet has added some weight to the argument that comets, once they are depleted of all their volatiles, turn into asteroids — or at least that they look like asteroids (see "Can Comets Become Asteroids?" ASTRONOMY, January 1985). Is there a defunct comet nucleus hiding in the Quadrantid stream? Possibly, but one thing is certain: the absence of an active comet to replenish the stream means that the Quadrantid's days are numbered.

The meteor stream that causes the Quadrantid shower was discovered in the 1830s by Adolphe Quetelet, the director of Brussels Observatory. He named it for the constellation containing the shower's

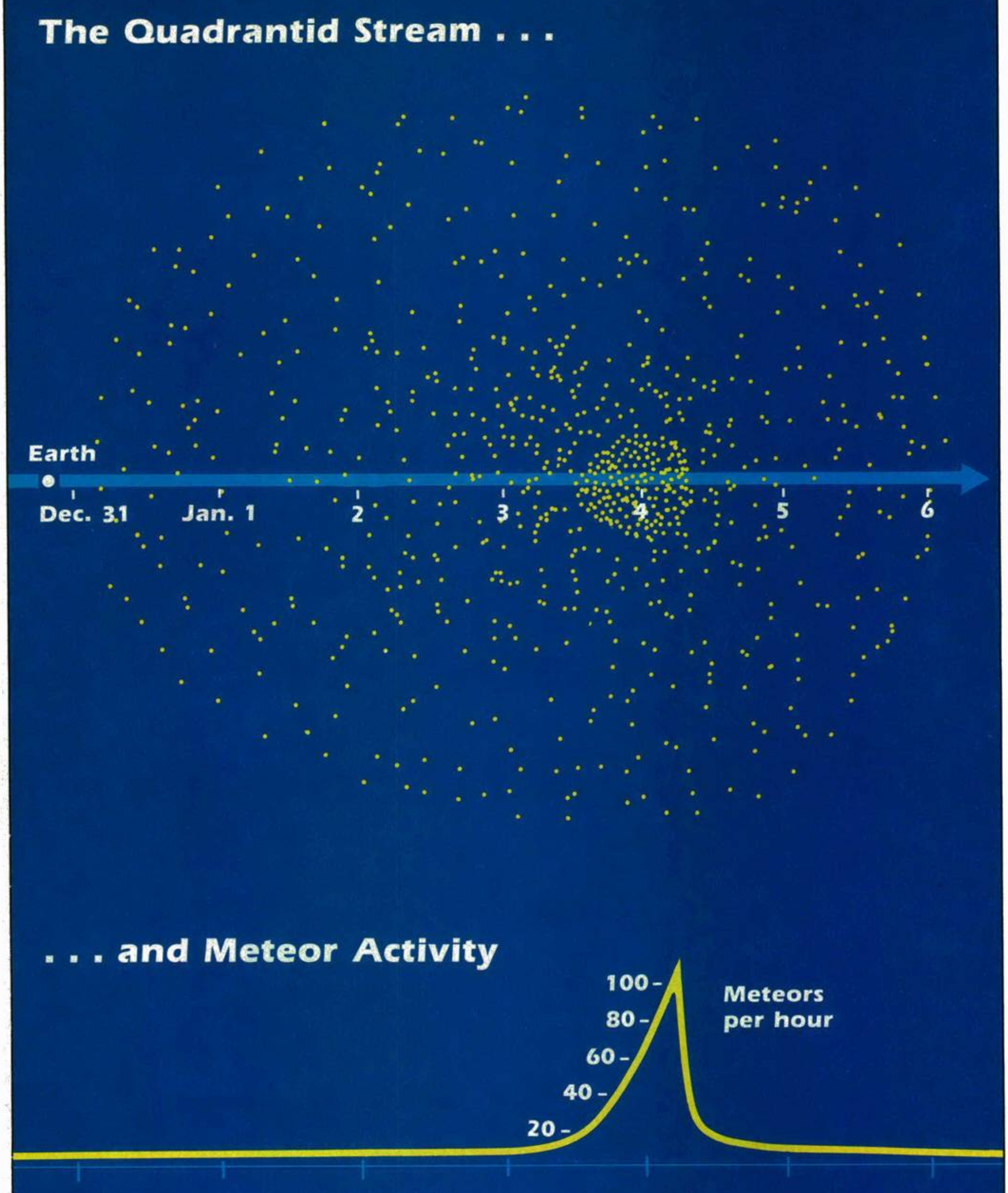
Of Meteors, Meteroids, and Meteorites

Meteor astronomy has a language all its own. To avoid confusion it's important to understand the sometimes subtle differences in the meaning of the terms used.

Meteoroids and *micrometeoroids* are small particles of interplanetary debris in orbit about the Sun. When one of these particles enters Earth's upper atmosphere (traveling at speeds ranging from 12 to 72 kilometers per second), it produces a streak of light called a *meteor*. (The term meteor applies to the luminous phenomenon alone — not to the bit of rock causing it.) When the meteor is brighter than magnitude −4, about as bright as Venus at its most brilliant, it is called a *fireball*. If the particles survive their fiery plunge through the atmosphere to land on Earth's surface, they are termed either *meteorites* or *micrometeorites*, depending on their size.

Oftentimes a large number of meteoroids share the same orbit, forming a *meteor stream*. A *meteor shower* results when the Earth passes through such a stream. All the meteors in an individual shower appear to radiate from the same area of sky, and the location of this *radiant* is normally used to name the shower. The Perseid shower is named for the constellation containing its radiant, Perseus; the Alpha Aurigid shower is named after a star near its radiant. Occasionally the shower is named after the comet with which it is associated (e.g., Halleyids). Meteors that do not belong to a stream are called *sporadics* and generally number about ten each hour under excellent conditions.

The number of meteors in a shower is measured by the *Zenithal Hourly Rate*, or ZHR, a theoretical value that is rarely achieved in practice. It is defined as the number of meteors an observer would see if the radiant was at his zenith and the faintest star visible had a magnitude of 6.5.



The Quadrantid Stream . . .

. . . and Meteor Activity

The sharp peak in the observed number of Quadrantid meteors is a direct result of the asymmetric shape of its meteor stream. A cross-sectional view of the Quadrantid stream (top) shows its characteristic oval shape and dense central core. When Earth passes through this stream in early January, we first witness a relatively slow but steady increase in meteors followed by a quick rise to peak activity and then a dramatic drop (bottom).

radiant: Joseph de Lalande's unpopular and now obsolete Quadrans Muralis. Located on the borders of Draco, Bootes, and Hercules, Quadrans Muralis continues to lend its name to the meteor shower despite the constellation's demise.

Observers in the United States and Europe later confirmed the existence of the stream and it quickly made a name for itself as the first major shower of the year. Even so, for over a century the Quadrantids were largely ignored by meteor watchers.

It was left to J. P. M. Prentice, the former Director of the British Astronomical Association's Meteor Section, to make the first detailed study of the stream. Analyzing observations from the period 1921 to 1953, he found a steady rise to maximum followed by a sharp, sudden fall — a profile that is still displayed today. He estimated meteor numbers to be in the range of thirty to forty per hour.

By the late 1960s it was obvious that the rate had increased substantially, to an average of 110 meteors per hour. This prompted Keith Hindley, one of Prentice's successors, to organize a special Quadrantid project. During the winters of 1970 and 1971 a total of 186 observers logged 7,785 meteors in 692 man-hours of observing! Participants in the project, mainly in the United States, Europe, and the Far East, were able to monitor activity continuously during maximum. Rates were a staggering 150 meteors per hour in 1970 and an estimated 105 per hour in 1971, making it the most active meteor shower of that time.

Understanding the Quadrantids

Hindley's research revealed many previously unknown facts about the Quadrantids. He established that the time of shower maximum occurs when the Sun's longitude is 282.83°, which is usually on January 3. (Astronomers in this field use a time system based on the Sun's longitude to pinpoint shower maximum and avoid the slight change in time that leap years otherwise induce.)

He also found that the relationship between the magnitude of a Quadrantid meteor and the length of time that its luminous trail, or train, is visible could be expressed by the simple formula:

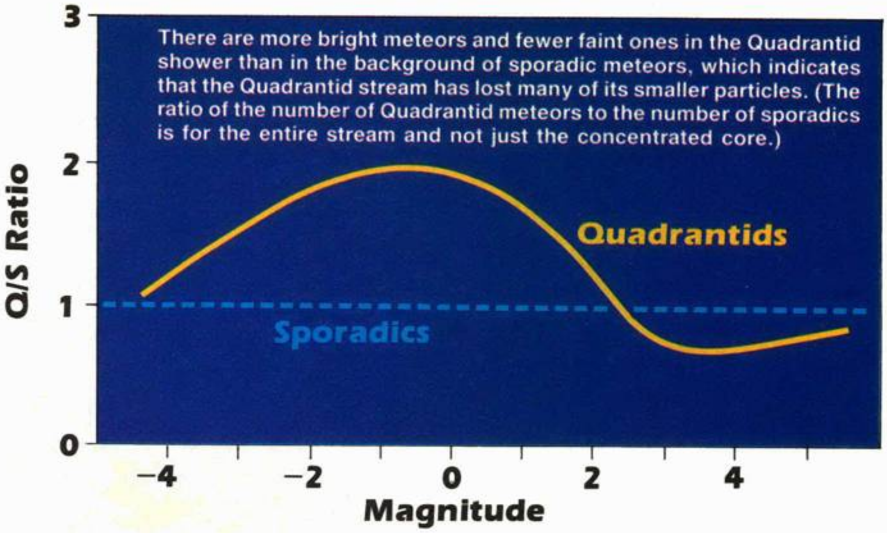
$$\log D = 0.09 - 0.19 \times m$$

where D is the train duration in seconds and m is the meteor's magnitude. What this means is that for every 1 magnitude increase in brightness, the duration of the train is increased by a factor of about 1.55.

Telescopic work — a field often neglected by meteor observers — also showed its value during the Quadrantid project. Observers reported that the meteors were pale blue with elliptically-shaped heads and dusty, silvery trains.

During the early and late stages of the shower the radiant had a very complex shape and was some 10° to 15° in diameter. At maximum the radiant contracted to less than 2°. The shower was also rich in meteors brighter than magnitude 1.5 when compared to the background of sporadic meteors.

Brightness of the Quadrantids



There are more bright meteors and fewer faint ones in the Quadrantid shower than in the background of sporadic meteors, which indicates that the Quadrantid stream has lost many of its smaller particles. (The ratio of the number of Quadrantid meteors to the number of sporadics is for the entire stream and not just the concentrated core.)

These factors suggest that the stream has lost many of its smaller particles as gravitational and nongravitational forces acted on the meteor stream. The smallest particles, those less than one-thousandth of a millimeter in diameter, are blown away from the Sun by solar radiation pressure and probably end up in the outer regions of the solar system. Larger particles, up to around a centimeter in diameter, are massive enough to overcome radiation pressure and remain gravitationally bound to the Sun. However, each of these particles absorbs and then reradiates solar radiation preferentially on the side facing forward in its orbital motion. This produces a drag force that causes the particle to lose orbital momentum and slowly spiral in toward the Sun — a phenomenon known as the Poynting-Robertson effect.

Gravitational forces can also severely disrupt the paths of meteoroids and micrometeoroids. For example, a stream with an orbit lying in the ecliptic and reaching out to 5 astronomical units (AU) from the Sun will periodically encounter Jupiter and have its particles "kicked" into new orbits. The net result of all these forces is to scatter the particles in the stream over a large area.

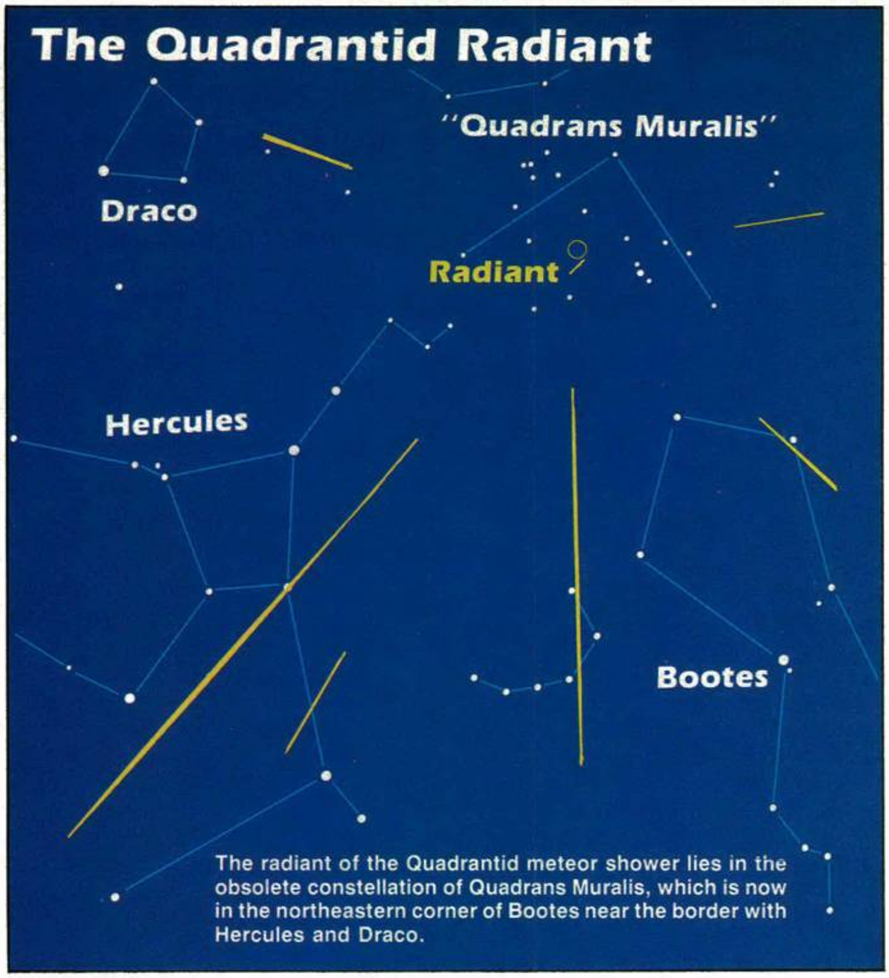
In the case of the Quadrantids, the outer fringe of the meteor stream is not symmetric around the core. The Earth first passes through the widely dispersed fringe, then meets its compact core, and finally exits through the more narrowly dispersed fringe on the opposite side of the stream. It is this asymmetric distribution that causes the observed meteor numbers to rise and fall as they do. But it also gives rise to a more subtle effect: the smaller, fainter meteors reach maximum rate before the brighter ones, with a one and one-quarter hour lag for each increment in magnitude.

The Quadrantid meteor stream is in a direct orbit around the Sun, the same direction as the orbital motion of the planets. As a result, the nodes of its orbit (the points where it intersects the ecliptic) drift backward along the ecliptic, which causes the stream to appear slightly earlier each year. (Retrograde orbits have forward-moving nodes that lead to a delay in maximum.) Although the rate of motion is quite small, amounting to only about 10 arcseconds of solar longitude each year, it advances the time of maximum by six and one-half hours each century.

S. E. Hamid and Mary N. Youssef have studied the behavior of several Quadrantid meteors whose orbital elements were precisely determined from photographs. By "backtracking" the orbit through the centuries they conclude that around 2000 B.C. a comet was captured by Jupiter's gravitational pull into a short-period, high-inclination orbit with a perihelion distance of 1.2 AU. The comet rapidly disintegrated and, over the centuries that followed, Jupiter modified the orbit of the resulting meteor stream into one with a low inclination and a perihelion distance of only 0.07 AU. At this distance the Sun's gravitational field strongly perturbed the stream particles, resulting in a very unstable situation. The stream's orbit has continued to evolve, increasing both in inclination and perihelion distance, to the values it has today.

David Hughes, an expert on meteor streams, estimates that the Quadrantids contain 4.6 million tons of meteoritic material, mostly in the form of dust. Together with I. P. Williams and C. D. Murray, Hughes has shown that between 200 A.D. and 900 A.D. the stream particles were so widely dispersed that they would not have given rise to a recognizable meteor shower. It is only within the last 150 to 200 years that the meteoroids have come together to form the stream Quetelet discovered.

Another interesting feature gleaned from extrapolating the Quadrantids back in time is that in about 500 A.D. the stream was in an orbit almost identical to that of



The Quadrantid Radiant

The radiant of the Quadrantid meteor shower lies in the obsolete constellation of Quadrans Muralis, which is now in the northeastern corner of Bootes near the border with Hercules and Draco.

the present-day Delta Aquarids (which are active in late July and early August). The similarity even extends to the appearance of individual meteors, which indicates that a relationship between the two is highly probable.

The Quadrantids in 1987

Because a New Moon occurs on the last day of 1986, the first week in January will be moonless in the after-midnight hours favored by meteor observers. The only catch is the weather. For much of the Northern Hemisphere January is the cloudiest month, and when the sky does clear off the air is often bitterly cold. These clear cold nights, however, are among the best for watching meteors.

If the weather is favorable, you can begin looking for the shower on New Year's Eve. The best time to observe will be on the evening of the 3rd and the morning of the 4th, as the shower reaches maximum. Because the time of maximum varies unpredictably from year to year it cannot be pinpointed exactly, but the best estimates place it at about 23h UT (6 p.m. EST) on the 3rd. (The actual time could easily be two to three hours on either side of this figure.) At this time the radiant will lie at right ascension 15h 28m and declination +50° (in 2000.0 coordinates), and the Moon will be only four days old. Since Quadrantid meteors typically enter the Earth's atmosphere at 43 kilometers per second, they will appear moderately swift. The expected ZHR is eighty meteors per hour, though many observers are hoping for a repeat of the 1985 display when as many as 235 meteors per hour were sighted. Once maximum has passed, the number of observed meteors will fall rapidly, returning to the background level by around January 6.

Observing the Quadrantids is really quite simple. The main thing to remember is that you need to keep warm and alert. Give yourself fifteen minutes to dark-adapt, then settle comfortably in a lawn chair and concentrate on the darkest area of sky, about 40° to 50° above the horizon and the same distance from the radiant. Every hour take a ten-minute break and have a warm drink and something to eat; these activities will keep you alert.

When you see a meteor — *freeze*. (This shouldn't be too difficult in sub-zero temperatures!) Try to memorize its color, length, and any noteworthy train features, and keep a written record of these along with the time of observation to the nearest minute. Make a magnitude estimate by comparing the meteor's brightness to nearby stars. If the weather cooperates so you have a run of clear nights, you should be able to find the sharp peak for which the Quadrantids are famous.

The Quadrantids are also an excellent target for astrophotographers. A standard 50mm lens is probably your best bet for recording the meteor shower: it covers a fairly large area of sky and is generally fast enough to record faint meteors. A wide-angle lens will cover more sky, but the slower lens is not as effective in capturing faint meteors; wide-angle lenses work particularly well near the time of maximum when the percentage of bright meteors is high. Use a film with a speed of at least 200 ISO and as large an aperture as possible. Lock the shutter open with a cable release and expose for 5 to 30 minutes. With luck you should capture at least one Quadrantid per exposure.

If you live in a town or in the suburbs where artificial lighting is a problem, pick a speed of about 200 ISO. If you use a faster film the background skyglow will fog the film fairly quickly, and you will be limited to short exposures. If you're lucky enough to live miles from the nearest town where skies are inky black, you can try a faster speed and leave the shutter open for much longer. If you've taken astrophotos before, let your experience dictate how long to expose before the background becomes unacceptable. (For the finer points of meteor photography see "Photographing Meteors in Winter," ASTRONOMY, November 1984.)

If you decide to keep an accurate record of your shower observations or to try your hand at photographing them, send them to one of the organizations listed. They will use your data along with those from other amateur observers in order to learn as much as possible about the Quadrantids. But you don't need to be a die-hard observer to enjoy this meteor shower. Spend a few minutes under the cold, dark sky and you might be rewarded with a sky streaked with the fiery demise of interplanetary dust.

Meteoric Addresses

If you want to learn more about meteors, send a large, self-addressed, stamped envelope to:

United States
American Meteor Society
David Meisel
Dept. of Physics and Astronomy
State University College at Geneseo
Geneseo, NY 14454

United Kingdom
British Meteor Society
R. A. Mackenzie, Director
26 Adrian Street
Dover
Kent CT17 9AT

Philip M. Bagnall lives in Wallsend, England, and is Director of the British Meteor Society's International Micrometeorite Research Network. A keen observer of meteors, he usually begins his watches at 4 a.m. after most observers have retired for the night.

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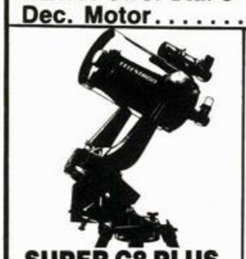

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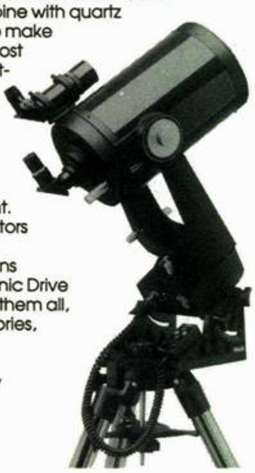

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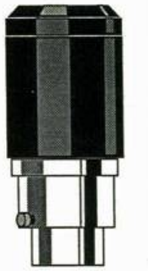

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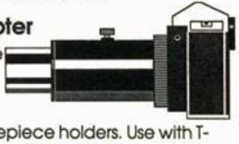

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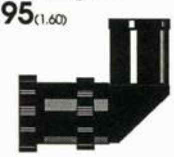

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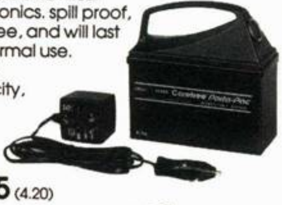

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Photography
in
Astronomy

Astrophotography without a Telescope

by Jim Baumgardt

Many people who might otherwise be interested in taking astrophotographs are often put off by all of the heavy, expensive equipment they think they need to do the job right. It's not as if they couldn't make long-exposure photographs of some obscure nebula even if they wanted to; these simple souls, instead, prefer not to deal with expensive weighted telescopes, drive systems, and exotic films and processing. Too many headaches and too much luggage.

Still, there is another kind of astrophotography that doesn't ask as much from your pocketbook or require a carload of sophisticated equipment. Much of what is beautiful in the sky to the unaided eye can be easily photographed with ordinary equipment. About all that is needed is a camera with a shutter that can be locked open for time exposures and a stable tripod.

This type of photography is as much art as science. A successful naked-eye photo not only portrays the astronomical subject but also combines an artistically pleasing foreground and uses color and composition to enhance the overall impact. Unhampered by heavy, complex equipment and capable of utilizing a wide variety of foregrounds, the "camera-only" astrophotographer is free to exercise his creativity and may experiment as he pleases. Here are some guidelines to get you started.

The time-honored advice to include a foreground object in your picture still applies here, but pick your foreground objects with care. Although a telephone pole adds scale and depth to a photo, many people won't find it aesthetically pleasing. I prefer to use natural objects such as trees, mountains, and clouds, or an astronomical foreground such as a telescope or observatory.

Star trail photos are easy to make and can be interesting when combined with a unique landscape. Simply load your camera with ISO 200 or faster film, mount your camera on a tripod, aim at the sky, and open the shutter. Because circum-

Photographing star trails can be more striking if you include an interesting foreground object. In this case, Lick Observatory was used. This was a 15-minute exposure using a 50mm lens at f/2.8 on Kodachrome 64 film. Photo by Jim Baumgardt.

Yosemite Falls by moonlight. Photo by Vernon Eugene Grove, Jr., who used an f/1.4 lens, Kodachrome 64 film, and an 18-second exposure.

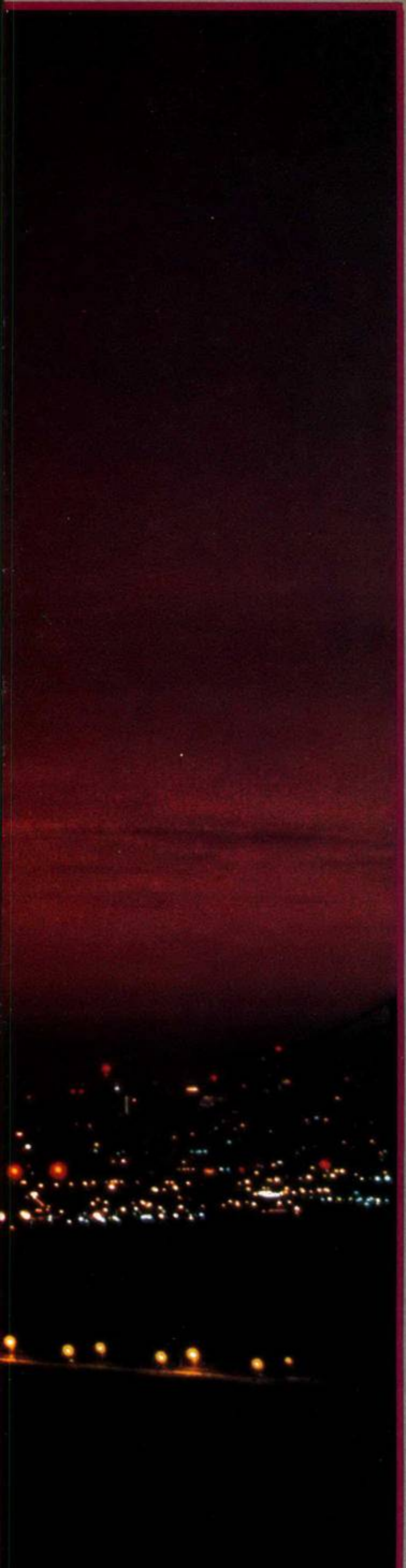
Orion rising over Old Faithful geyser in Yellowstone National Park, Wyoming. The foreground light was provided by a gibbous Moon. Photo by Dewey Vanderhoff.

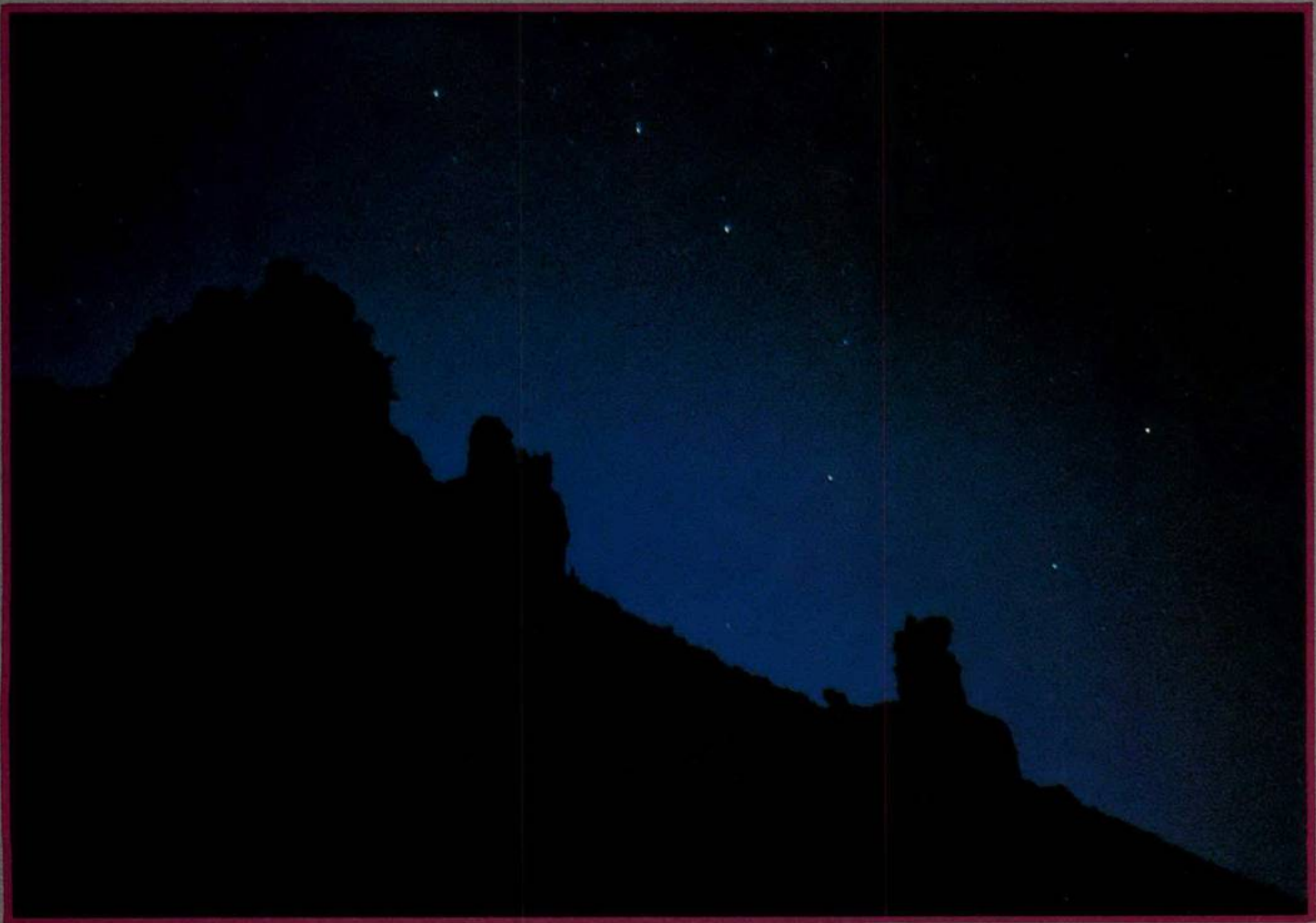
A compelling perspective on land, sky, and distance is captured in this photo of a conjunction of the Moon, Venus, and Jupiter by Jim Baumgardt.

Manmade and celestial architecture are eloquently combined for this scene of the Moon, Venus, and Jupiter, taken by Frank Zullo, who used a 100mm lens at f/2.8, Kodachrome 64 film, and a 6-second exposure.

This 1-second exposure of moonrise taken at deep dusk was made with a 200mm lens at f/4.5 on Kodachrome 64 film. Photo by Jim Baumgardt.

Ursa Major poised above the rugged mountain profile at Clocktower Creek, Wyoming. Photo by Dewey Vanderhoff.





Maximum Starfield Exposures

(In seconds, to produce round star images)

	Lens Focal Length (millimeters)									
	18	**28**	**35**	**50**	**90**	**135**	**200**	**400**	**600**	**1000**
Circumpolar	67	43	34	24	13	9	6	3	2	1
45 degrees from pole	50	32	26	18	10	7	4.5	2	1.5	1
Celestial equator and ecliptic	33	21	17	12	7	4.5	3	1.5	1	0.5

Exposures for the Moon

(In seconds, at f/8)

	Film Speed (ISO)							
Lunar Phase	**10**	**25**	**64**	**100**	**200**	**400**	**1000**	**2000**
Thin Crescent	1/2	1/8	1/15	1/15	1/30	1/60	1/125	1/500
Thick Crescent	1/4	1/15	1/30	1/30	1/60	1/125	1/250	1/1000
First or Last Quarter	1/8	1/30	1/60	1/60	1/125	1/250	1/500	1/2000
Full	1/15	1/60	1/125	1/125	1/250	1/500	1/1000	—

polar star trails are concentric, they can be striking with or without a foreground. But stars near the celestial equator need a well-placed stand of trees or a moonlit waterfall to complement their straight trails and to give the sky a sense of motion. In both cases a dark sky is necessary to keep sky fog low and contrast high, especially if you are using a fast film.

To record a star field with a minimum of trailing, exposures must be kept short. This requires a fast lens and fast film. For example, when you use ISO 400 film, the bright stars of a constellation should record in a few seconds. With a 50mm lens, stars nearest the celestial equator won't begin to show trails until after about 12 seconds; stars nearest the poles won't show appreciable trailing until after about 24 seconds. The table at the top of the page is a guide to the maximum exposures that will record stars as points. Since visual appearance is important in this type of photo and fast film tends to be too grainy with long exposures, I use the slowest film that will do the job.

The same foreground guidelines discussed with star trails apply here also. Consider incorporating dawn or dusk colors in the star field. This will nicely profile your foreground objects as well as record subtle gradations in twilight color. Here again experimentation is invaluable.

Artists and photographers have always used the Moon to enhance paintings and photos of natural scenes. Turning that around, I believe that natural scenes and even some manmade objects can enhance photos of the Moon. However, since the Moon is only half a degree across, you'll probably need to make the lunar image appear somewhat bigger than it is. Photos of the Full Moon taken with a 50mm lens show its true size: it appears as a bright, half-millimeter dot on the film. Telephoto lenses of about twice this focal length, 90mm to 105mm, render a 1-millimeter image of the Moon; doubling that focal length gives you an image exactly twice that size. You can also have the image enlarged to show even more detail.

The second table is a guide to the proper exposures for the Moon. If the Moon is photographed during twilight or dawn, the exposure can be balanced by setting your camera for the proper exposure for the Moon and then using the camera's light meter to determine the exposure for the rest of the scene. The shot will be best when the foreground is two to three stops underexposed, based on the exposure for the Moon. Take several shots and bracket your exposures just to be sure.

Lunar and planetary conjunctions are also excellent subjects. Use the same techniques for capturing star fields and, of course, include foreground objects if possible. Moon and planet conjunctions taken with long telephotos can stand alone, but they are real eye catchers when creatively combined with appealing foreground objects.

The technique of photographing meteors is similar to that of photographing star trails, though it is slightly more complicated because of the unpredictable nature of meteors. Your chances of capturing a meteor on film will be better during a meteor shower when the radiant is high overhead. Use a normal lens as opposed to a wide-angle lens, since the smaller image scale can better record fleeting streaks of light. A low-grain slow film like Ektachrome 200 is more desirable than faster film since you want the film to respond to the sudden bright streaks of light without being too susceptible to sky fog. Exposures will depend on how dark your sky is and the speed of film you are using. Longer exposures will obviously record more meteors, but if you are near a city these longer exposures will also record too much light pollution and the meteor trails will be blotted out. A lens opening of f/4 and exposures in the quarter- to half-hour range will be adequate for the average dark sky.

Aim your camera at the shower's radiant and open the lens. When a bright meteor flashes across the camera's field of view, advance the film and start a new exposure, otherwise you run the risk of diminishing the meteor's track in sky fog.

Large bright comets captured with an interesting foreground or perhaps in a colorful dawn or dusk sky can make a masterpiece. Use the maximum exposure possible without allowing the stars to trail. For best results, note the comet's predicted location and match it with the foreground of your choice. To increase your chances for success, do this before the appearance of the comet and take trial photos of the scene so you will be ready when the time comes.

Astrophotography with a camera and a tripod can be both pleasurable and challenging, and it can produce satisfying results without the sizable investment in equipment telescopic astrophotography involves. It also gives you valuable experience in dealing with the cause-and-effect relationships of exposure times and film speeds, which will come in handy if you ever decide to go deeper into astrophotography.

Jim Baumgardt is an astrophotographer living in Burlingame, California. His latest photo appeared in the Eye on the Sky column in the November issue.

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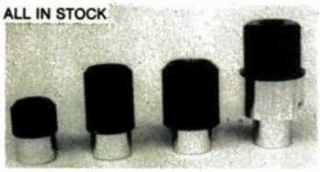

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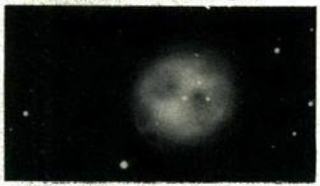

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48mm "Horsehead Nebula" H-BETA Line Filter		$189.50
Oxygen-III Filter for very faint planetary and diffuse nebulae, 11nm bandpass at 496nm and 501nm 0-III lines	1¼" $99.50,	48mm $199.50
Telephoto lens adapter for 2" or 48mm filter. Select 46, 49, 52, 55, 58mm		$6.95
Universal adapter for 1¼" filters. Adapts the 1¼" filters to any 1¼" eyepiece		$16.00
Universal adapter for 48mm or 2" filters. Allows use of any 1¼" eyepiece		$20.00

**Premium filters are selected best of the lot and typically have 5-10% higher transmission. Not always available. Include individually measured transmission data.*

DEEP-SKY ASTROPHOTOGRAPHY

FILM HYPERSENSITIZATION KITS†

LUMICON HYPER-KITS™ yield 3-15X film speed gain in long exposures. They are safe & simple to use. Easy HYPER-KIT includes a chamber with all controls and fittings, thermometer, a refillable cylinder of non-flammable forming gas & hand-operated vacuum pump.

U.S. Patent 4,473,636

MAKE YOUR OWN HYPERED FILM

MODEL 300 HYPER-KIT sensitizes any 35mm film in hours. Best for 2415. Achieves highest possible film speeds $295.00

MODEL 600 HYPER-KIT [See Photo] Like the Model 300, but also sensitizes 120/220 larger format film and small glass plates $350.00

MODEL 1200 HYPER-KIT is for 4X5" plates and film up to 5X7". Has 2 gas cylinders and includes temperature controller . . $595.00

Temperature controller for any HYPER-KIT $59.50

Electric Vacuum Pump, Model R-10 $280.00

GUIDE OFF-AXIS FOR LOVELY ASTROPHOTOS

All **LUMICON EASY-GUIDER™** off-axis guiders† have both radial and 360° rotational adjustments for 5X eaiser guide-star selection, use 48mm filters, 360° camera rotation, large prisms fo bright guide-starts. *Specify Camera and Telescope type.*
U.S. Patent # 4,448,500

NEWTONIAN EASY-GUIDER™

Full aperature. Installs in secs. Specify 2" or 1¼".

NEWTONIAN EASY-GUIDER	$169.50
3X Relay Diagonal (see photo)	$79.50
Illuminated reticle eyepiece system	$79.50

Guider for Hasselblad **$350,** Mamaya 645 **$199**

CASSEGRAIN EASY-GUIDER™

For C-8, Meade 2080, Dynamax-8. Includes 50mm achromatic lens for f/5.8 operation-3X shorter exposures! **Superb rich field viewing, too!**

CASSEGRAIN EASY-GUIDER $225.00
Adapter for Hasselblad **$185,** Mamaya 645 **$159**

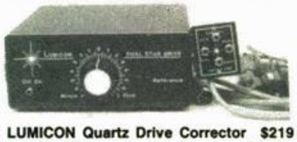
GIANT EASY-GUIDER™

For Celestron-11, C-14, and the 10" Meade 2120. Includes 80mm clear aperture achromatic lens for edge-to-edge illumination & pin-point star images. F-ratio adjustable f/4-f/11. **Also yields unmatched Rich-Field viewing.**

GIANT EASY-GUIDER $395.00
48mm DEEP-SKY Filter ordered with any EASY-GUIDER (SAVE $20) . . . . . . **add $99.95**
Adapter for Hasselblad **$195,** Mamaya 645, **$96**

WHAT DO YOU NEED?

1. **Illuminated reticle eyepiece** . . . $79.50
Lumicon 12mm eyepiece system has adjustible L.E.D. illumiation, dual crosslines, battery pack.
2. Cable release for long exposures. **$9.95**



3. **LUMICON Quartz Drive Corrector $219**
Dual-axis drive corrector is essential for astrophotography and/or field use of your telescope. 40Hz/80Hz variable output controls telescope drive. 60Hz Quartz reference ±12VDC Declination control output. Both 110VAC and 12VDC input for home or field use. Declination reverse switch for Newtonians.

Declination motor (state telescope) . . $70
NEW Deluxe Digital Qtz. Drive Correc. **$298**

HYPERSENSITIZED FILM

LUMICON Hypersensitized film is essential for good deep-sky astrophotography. Deduct 10% for 3 or more rolls (mixed o.k.).

Film Type, 35mm	Exposures	Price
2415, Ultra-fine B&W, red sens.	36	$10.95
SR1600, fastest of all, color neg	24	$12.95
Konica SR200, fine grain color neg	12	$9.95
3M 1000, fastest slide film	20	$12.95
Fujichrome RD100, fine grain slide	24	$12.95
5072, color slides from neg	36	$6.95
D-19 B&W Developer	1 gal.	$6.95

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LUMICON Products catalogue $2.
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Hrs: M-F 9am - 5pm; Sat 11am - 3pm

Meade® TELESCOPES AT LUMICON

MEADE 2080/LX3 w/MCSO $1685

#712 Dew shield (8") and accessory tray ($140 list) **add $89**

MEADE 2120/LX3 w/MCSO $2590

Accessory shelf for field tripod ($40 list)	**$32**
#710 dew shield (10") Essential! ($140 list)	**$98**
#36 dual-axis drive corrector control box ($150 list)	**$99**
#38 declination motor and clutch ($150 list)	**$99**
LUMICON Giant EASY-GUIDER/Rich-Field viewer for f/4-f/10 operation (state camera)	**$395**

2080/LX3
$1685
2080/LX3
W/MCSO

NEW! Quartz Drive Meade 2080/LX3

The Meade 2080/LX3 with built-in quartz electronic drive system is positively the highest performance 8" Schmidt-Cassegrain telescope system available today.

2120/LX3 10" System w/MCSO $2590

The 10" Meade 2120/LX3 collects 56% more light than an 8" telescope for significantly improved viewing and astrophotography. It has all the features of the 2080/LX3 (see Meade ads in this magazine for full list of features.)

4" MEADE 2045 w/table tripod $695

NEW! Meade 2045/LX3 w/quartz drive **$885**

IN STOCK!
Meade
NEW!
2045/LX3

Meade Model 2045 — Advanced engineering and superb optical performance in a beautiful ultraportable system.

FEATURES OF THE MEADE 2045

- ★ 4" f/10 Schmidt-Cassegrain optics, F=1000mm
- ★ Motor drive for automatic tracking, 110 VAC input
- ★ **LX3:** quartz-controlled elec. drive, 12VDC or 110VAC input
- ★ High transmission coatings on front corrector lens
- ★ Table tripod for easy polar alignment
- ★ 5X24 finderscope & 1¼" right-angle star diagonal
- ★ 1¼" 25mm (40X) and 9mm (111X) eyepieces
- ★ Fork mount with setting circles, manual slow motion

HIGHLY RECOMMENDED OPTIONS

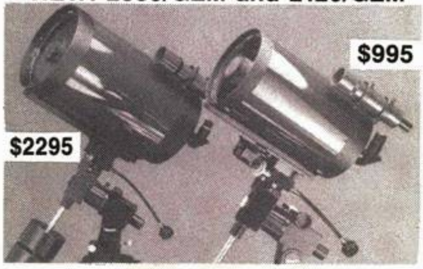
Model 43 drive corrector uses 12VDC ($120 list)	**$96**
See Meade 2080/LX3 options	
Wedge & field tripod for Meade 2045 ($380 list)	**$298**
Dew shield ($70)	**$49**
Solar Filter ($180)	**$139**

TELESCOPE SALE

Meade
THE LEADER'S EDGE
Authorized
Meade
Dealer
Sale ends
12/31/86
ONLY
$698!

Meade Model 628 6" f/8 **w/motor,** 1¼" focuser, 6X30mm finder ($1226 list)	**$698**
Meade Model 628C 6" f/8 **w/motor,** 2" focuser, 8X50mm finder ($1450 list)	**$798**
Celestron-11 with Starbright coatings	**$3250**
Celestron Super Polaris SP-C8, 8" f/10 on equatorial mount w/high transmission coatings ($1950 list)	**$1095**
Celestron CO-114, 4½" f/9 reflector & mount	**$425**
Meade Model 310, 80mm f/11 refractor ($800 list)	**$449**
Meade Model 107-D 4" f/10 spotting scope	**$429**

NEW! 2080/GEM and 2120/GEM



Schmidt-Cassegrain Optics on German Equatorial Mount

2080/GEM, 8" f/10 w/equatorial mount ($2100 list)	**$995**
Multi-coated silvered optics, boost transmission 18%	**add $149**
2120/GEM, 10" f/10 w/equatorial mount **and with multi-coated silvered optics** ($4300 list)	**$2195**
Dew shield & accessory tray, 8" .... **$72** 10"	**$144**
#785 motor and quartz drive correc. system ($270 list)	**$198**
#3000 computer control system ($1500 list)	**add $949**

The Meade 2080/GEM and 2120/GEM telescopes include the same diffraction limited optics as the 2080/2120/LX3. Large, stable German equatorial mount with setting circles, slow motion controls on both axes, large 8X50mm finderscope, 25mm 1¼" eyepiece, integrated polar alignment scope, and heavy duty adjustable height tripod (hardwood for 2080, metal for 2120). The computer control provides automatic object location from an extensive software library of deep-sky objects.

OPTIONS BOOST PERFORMANCE

LUMICON UHC Filter for nebulae. Standard 1¼"	**$79**
Prem 1¼", **$99;** Std 48mm, **$159.50;** Prem 48mm,	**$199.50**
LUMICON Deep-Sky Filter, 1¼" Premium	**$79**
48mm Prem Deep-Sky ..... **$119.50, $99.95** w/Easy-Guider	
Adapter for viewing w/1¼" eyepiece	**$20**
Dust covers. Keep optics clean. For 6"	**$16/pair**
8" .... **$20/pair;** 10" .... **$18;** 16"	**$24**
LUMICON Rich-Field Viewer (2080)	**$140**
LUMICON Newtonian Easy-Guider, 1¼" or 2"	**$169**
#122 2X Barlow ($60 list)	**$48**
Dual-axis drive corr. and elec. dec. for 2080/LX2	**$298**
for model 628, 826, DS-10 .... **$340** for DS-16	**$440**
Tele Vue 32mm Plossl 1¼" eyepiece	**add $99**
LUMICON Cassegrain EASY-GUIDER for Meade 2045, 2080/LX3 and 2080/GEM (state camera)	**$225**
Illuminated reticle eyepiece & battery pack	**$79.50**

All foreign orders add 6% ($8 minimum)
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All telescopes shipped F.O.B. Livermore

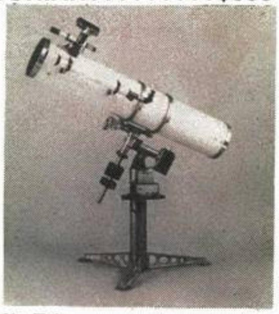
8" f/6 NEWTONIAN.........$995

SALE

$698
(Model 628)

$798
(Model 628C)
6" f/8 with
motor drive

Sale ends
12/31/86



Model 826, 8" f/6 Telescope w/accessories

Model 628, 6" f/8 with motor drive ($1220 list)	**$698**
Model 628C, 628 w/2" focuser, 8x50mm finder ($1450	**$798**
Model 826C, 8" f/6 with motor drive, #680 2" focuser and 8x50mm finderscope ($1590 list)	**$995**

—Collects 78% more light than a 6" telescope.

These Meade Deluxe Series reflecting Telescopes have superb image quality at low or high power. They include an equatorial mount with motor drive, pier, legs, setting circles, 2" rack & pinion focuser, 8X50 finderscope (628C & 826C only), 25mm (48X) and 9mm (135X) 1¼" eyepieces, altitude and azimuth fine adjustments for polar alignment.

#43 drive corrector uses 12VDC ($120 list)	**$96**
#47M Dual-axis drive corrector & elec. dec.	**$340**
1¼" or 2" EASY-GUIDER (state camera)	**$169**

6" f/5 NEWTONIAN........$695

IN STOCK!

STILL AVAILABLE AT 1985 PRICES!

Models 6600 (6" f/5) & **8800** (8" f/4.5) telescopes

Model 6600, 6" f/5 Newtonian telescopes ($1300 list)	**$695**

—Best performance & value; bright, wide views.

Model 8800, 8" f/4.5 Newtonian Telescopes ($1700)	**$895**

—Collects 78% more light than a 6" telescope.

These Meade Professional Series reflecting telescopes yield superb rich-field viewing w/bright images. They include an equatorial mount w/adjustable tripod, setting circles, slow motion controls, 6x30mm view-finder, 1¼" focuser, 25mm & 9mm 1¼" eyepieces & accessory tray.

#784 motor & quartz drive corrector ($270 list)	**$198**
Basic camera adapter (for moon & planets)	**$32**
1¼" LUMICON Easy-Guider (state camera)	**$169**

16" f/4.5 NEWTONIAN......$1995

STILL AVAILABLE AT 1985 PRICES!

Meade DS-16A with Accessories

The DS Series of 10" and 16" reflecting telescopes are ideal for deep-sky viewing and photography.

DS-10A, 10" f/4.5 with motor drive ($1600 list)	**$995**

—Gathers 56% more light than an 8" telescope

DS-16A, 16" f/4.5 with motor drive ($3140 list)	**$1995**
Sealmaster ball bearings, highly recommended	**add $229**

—Gathers 400% more light than an 8" telescope

Both the DS-10A and DS-16A telescopes include an equatorial mount, #680 2" focuser, motor drive, setting circles and 25mm 1¼" eyepieces. The DS-10A is shipped freight collect.

6x30mm finderscope with brackets ($56 list)	**$42**
8x50mm finderscope with brackets ($130 list)	**$96**

Eye on the Sky

Venus Meets Saturn

by Robert Burnham

The Wanderers

This month the early evening sky contains two planets. **Jupiter** is the conspicuous white object in the southwest, shining brightly at magnitude −2.2. In the late twilight it stands above the horizon about as far as a foot ruler held at arm's length. Since Jupiter is among the stars of Aquarius and Pisces, it is easy to locate, being the brightest "star" in the area. (If you have binoculars, try to spot the four star-like Galilean moons that closely flank Jupiter. Notice how they change their positions nightly.)

Poised at Jupiter's upper left, **Mars** is substantially fainter (magnitude 0.8) and has an amber tint markedly different from Jupiter's white gleam. Thanks to the dim surrounding starfields, however, Mars stands out almost as clearly as Jupiter does. Like all planets Mars appears to move relative to the stars — but Mars' motion is particularly rapid. Because they are dim and scattered, the stars in this part of the sky make poor reference points, but from week to week notice how the distance between Mars and Jupiter grows.

Late in January **Mercury** creeps into the evening sky. By the end of the month it will hover in the trees a few degrees above the southwestern horizon during the hour after sunset. If you look carefully but can't find it, don't worry — by the middle of February Mercury will have climbed higher and will be easier to spot.

After 11 p.m., when Mars and Jupiter have set, no naked-eye planet is visible until Venus rises around 4 a.m. The best time to look for morning planets, however, is the hour before sunrise, because then they are at their highest and the sky remains dark enough to reveal them.

On January 15 **Venus** will be at its greatest apparent distance from the Sun. Lying 47° west of the Sun and shining at magnitude −4.4, Venus is an easy-to-find, brilliant white object among the stars of Scorpius, which are faintly visible in the background as morning twilight brightens.

Even though it is about half as high as Mars in the evening sky, Venus is still bright enough to cast a faint shadow. An hour or two before sunrise, find a patch of clean snow (or a light-colored surface) that faces Venus and is shaded from street, porch, or moonlight. Hold your mittened hand a few inches in front of the surface of the snow and wave it back and forth. Although you may not be able to see the shadow if you hold your hand still, motion usually reveals it.

For information on viewing the Moon, planets, and deep-sky objects with telescopes, see **The Backyard Astronomer**.

On January 24 Venus will pass less than 2° (about four Moon-diameters) north of 0.5-magnitude **Saturn**. If weather permits, observe the pair over several mornings so you can see their day-to-day motion. Naked-eye views are fine but many people will use binoculars for closer looks. There are good photo opportunities here, too. Use a medium to high-power telephoto, fast film, a tripod, and exposures of 1, 2, 5, and 10 seconds. Try to include some foreground trees or houses for added perspective.

Be sure not to confuse Saturn with the star Antares. Although both are about equally bright, Saturn lies closer to Venus and looks whiter.

January's best meteor shower, the **Quadrantids**, reach their brief peak of activity on the night of the 3rd and morning of the 4th. Look for about twenty to thirty meteors an hour from the region between the head of Draco and the handle of the Big Dipper. For complete details see Gazer's Gazette on page 39.

Above: Cassiopeia is a bright circumpolar constellation in winter and a favorite subject for star-trail photographs. Photo by Richard Hunt.

Right: This photograph of the rising Moon and its watery reflection was taken with a 100mm lens at f/4 and a 1/30-second exposure on Ektachrome film. Photo by A. W. Steinbrecher.

The Starry Sky

January nights are usually the year's coldest but they also produce the best sights. So, warm up the car, bundle on the layers, fill a large thermos with coffee or cocoa, grab your ASTRONOMY (and perhaps a pair of binoculars), and tuck a red-lensed flashlight into a warm pocket under your coat. The only way to really *see* those sights is to drive a dozen miles out past the streetlights.

Find a little-used back road that has good visibility all around — perhaps a spot where the road crosses a small hill or runs between two large fields. As you step out of the car's warmth, tug the knit cap down over your ears and tighten your scarf. Your breath will puff out in clouds as your boots softly crunch the packed dry snow at the road's edge.

Looking up at the southern sky you see **Orion** the Hunter chasing his endlessly-retreating adversary, **Taurus** the Bull. The

January Night Sky

First Quarter
January 6
5:34 p.m. EST

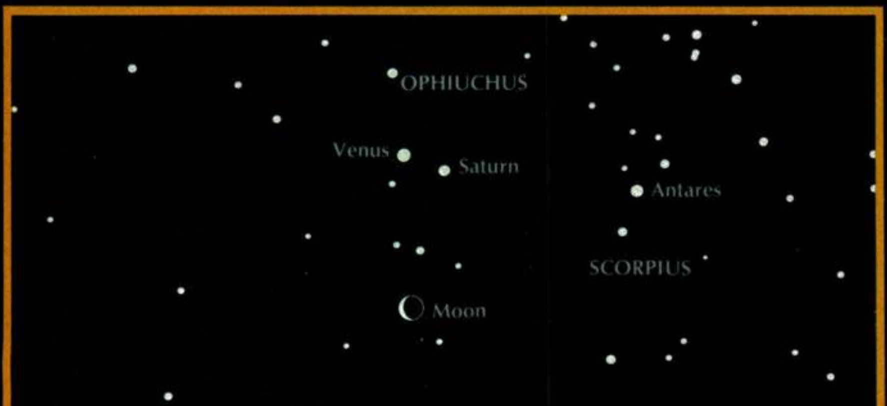
Full Moon
January 14
9:30 p.m. EST

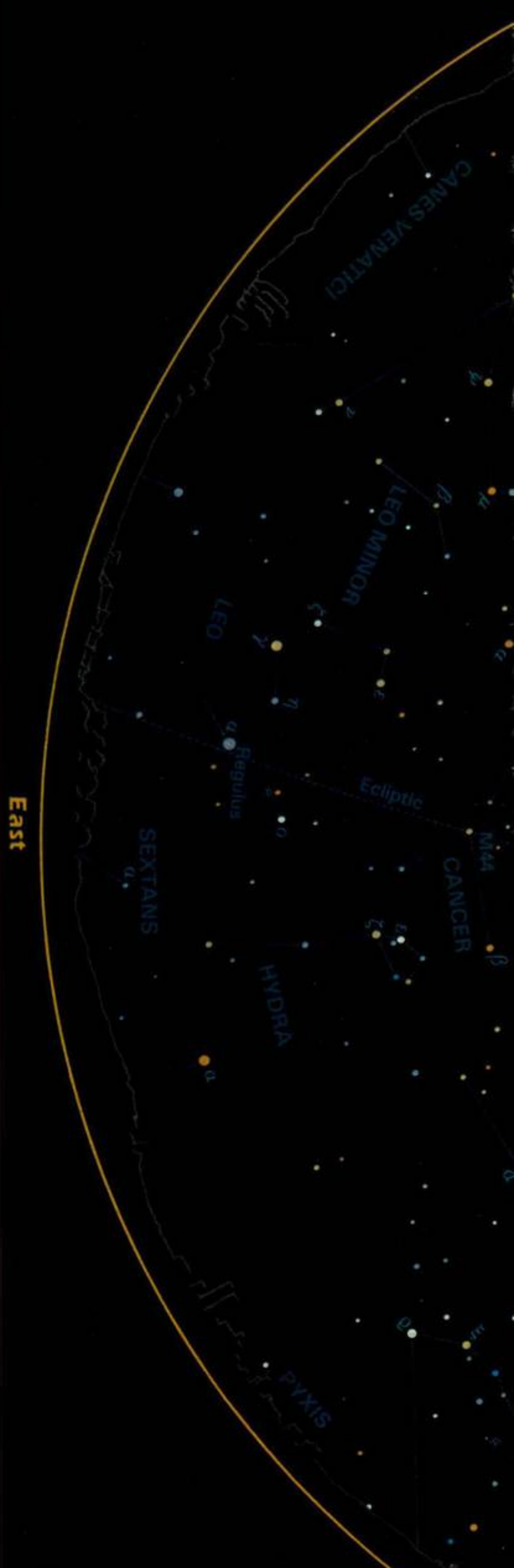
Last Quarter
January 22
5:45 p.m. EST

New Moon
January 29
8:44 a.m. EST

4th	Earth is closest to the Sun: 0.983301 astronomical unit (147 million kilometers). Peak activity for the Quadrantid meteor shower (see Gazer's Gazette on page 39).
5th	Mars lies 1.4° north of the Moon.
6th	First Quarter Moon occurs at 5:34 p.m. EST.
12th	Mercury passes through superior conjunction. It will be visible low in the evening sky starting in about two weeks.
13th	The Moon is farthest from Earth at 12:00 a.m. EST: 252,525 miles (406,401 kilometers).
14th	Full Moon is at 9:30 p.m. EST.
15th	Venus is at greatest elongation west of the Sun, 47°. Look for it in the southeast during the hour before sunrise. It also lies 8° north of the star Antares in Scorpius today.
22nd	Last Quarter Moon occurs at 5:45 p.m. EST.
24th	Venus lies less than 2° north of Saturn in the predawn sky.
26th	The Moon will lie near Saturn and Venus this morning.
28th	The Moon is closest to Earth at 6:12 a.m. EST: 218,674 miles (358,894 kilometers).
29th	New Moon is at 8:44 a.m. EST.

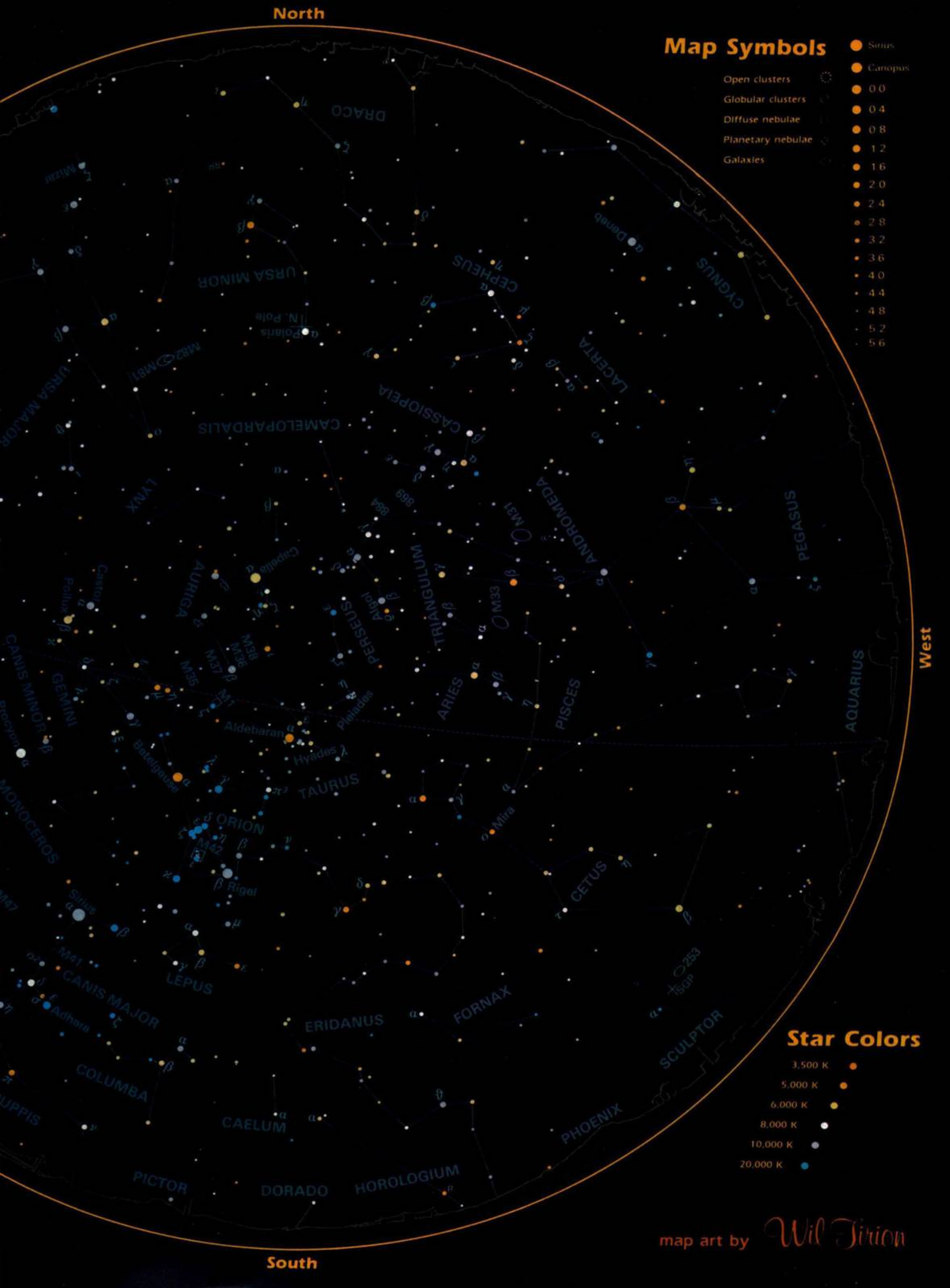
Looking southeast January 26, before sunrise





The Star Dome shows how the sky looks at:

10:00 p.m. on January 1
9:00 p.m. on January 15
8:00 p.m. on January 31


North
West
South
Map Symbols
Sirius
Canopus
Open clusters
Globular clusters
Diffuse nebulae
Planetary nebulae
Galaxies
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
Star Colors
3,500 K
5,000 K
6,000 K
8,000 K
10,000 K
20,000 K
DRACO
URSA MINOR
N. Pole
Polaris
CEPHEUS
Deneb
CYGNUS
LACERTA
M82
M81
URSA MAJOR
Mizar
CAMELOPARDALIS
CASSIOPEIA
LYNX
ANDROMEDA
M31
PEGASUS
884
869
Capella
AURIGA
Castor
Pollux
PERSEUS
Algol
TRIANGULUM
M33
M38
M36
M37
M35
CANIS MINOR
GEMINI
Procyon
ARIES
PISCES
AQUARIUS
Pleiades
Aldebaran
Hyades
Betelgeuse
TAURUS
MONOCEROS
ORION
M42
Mira
Rigel
CETUS
Sirius
M47
M41
LEPUS
CANIS MAJOR
Adhara
253
SGP
FORNAX
ERIDANUS
SCULPTOR
COLUMBA
PUPPIS
CAELUM
PHOENIX
PICTOR
DORADO
HOROLOGIUM

map art by Wil Tirion

Hunter stands poised with a lionskin shield depicted in the many "pi" stars (the map labels only π^3). Warm-hued Betelgeuse marks the shoulder of the upraised arm wielding a club. Across Orion's wasp waist lie the three stars that form his belt: Zeta (ζ), Epsilon (ε), and Delta (δ). Hanging from the belt is his sword, containing the Great Nebula, M-42. Blue-white Rigel and Kappa (κ), also called Saiph, are his two knees.

Taurus is only the front half of a bull. We can pick out his face in the V-shape of the Hyades cluster, one angry eye in Aldebaran, and two horns extending eastward to Beta (β) and Zeta (ζ). You can also imagine a shoulder at the Pleiades cluster and a foreleg passing through Lambda (λ).

Directly below Orion lopes a wary Hare, **Lepus**, momentarily ignored by Orion's faithful Dog, **Canis Major**, who is rearing up to paw the Hunter. Sirius, the head of Canis Major, is the brightest star in the sky and lies only 9 light-years away from the Sun. M-41 below Sirius is a star cluster just visible to the naked eye; in binoculars it looks like a hazy patch.

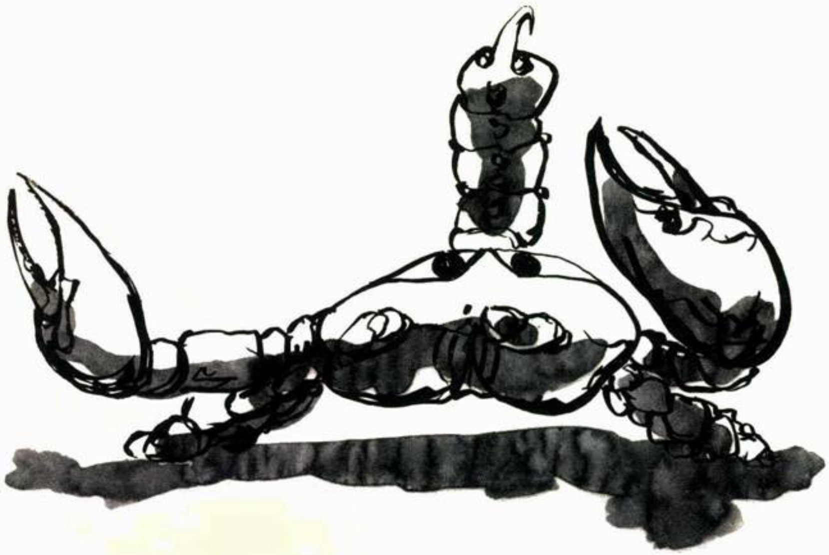
Drawing a line from Rigel across Orion to Betelgeuse and extending it the same distance again puts you in the middle of **Gemini** the Twins, marked by the stars Castor and Pollux. Gemini and Taurus both belong to the zodiac — the twelve constellations that line the ecliptic, the apparent path taken by the Sun in the course of a year. If you face east, you'll see another zodiacal figure lying below Gemini: **Cancer** the Crab, which we'll see better in the spring.

Straight north of Taurus, the Charioteer **Auriga** wheels slowly along the Milky Way. Auriga forms a pentagon and contains three small clusters for binoculars: M-36, M-37, and M-38. Due west of Auriga lies **Perseus** the Hero, who rode **Pegasus** the Flying Horse to rescue **Andromeda** the Maiden from the wiles of **Cetus** the Sea-Monster, and restored her to her parents, **Cassiopeia** the Queen and **Cepheus** the King (of Ethiopia). Andromeda is home to M-31, a large spiral galaxy dimly visible to the naked eye and a beautiful sight in binoculars.

Tracing the ecliptic west from Taurus would ordinarily be difficult because the stars along its path are dim. But at present we have two bright planetary beacons — Mars and Jupiter — marking the way through **Pisces** the Fishes and **Aquarius** the Water-carrier.

Top left: Two years ago Venus, Jupiter, and the waning crescent Moon provided a striking composition in the dawn sky near Cody, Wyoming. Ranch buildings are silhouetted in the foreground. Photo by Dewey Vanderhoff.

Bottom left: Seen from eastern Canada, the Moon covered about 80 percent of the Sun at maximum during the October 3, 1986, annular solar eclipse. This photograph was taken by William Halushak from New Brunswick, Canada, using a 400mm lens at f/16 and a 1/1000-second exposure on Fuji 400 film.



By now all warmth has oozed from your feet and your hunched shoulders are cramped with the effort of keeping cold air from knifing down your neck. So let's finish with a quick look at the **Milky Way**. If you recall last summer's skies, you can't help noting how much richer the Milky Way was then. Tonight's version is dim and hard to follow in places. The reason is that when you look up toward Gemini and Auriga, you are looking directly away from the teeming hub of our galaxy toward the thinly-populated galactic rim. It's like wandering away from a noisy party to stand in the front doorway — behind you throngs the crowd while before you stretches a cold, empty expanse.

Skylore

When we left him last month, the sightless Orion, blinded by King Oenopion for ravishing his daughter, had just had his vision restored by the rays of Helios, the Sun god. Helios was also brother to Eos, goddess of the dawn. She was in love with Orion and dallied with him for a while on the island of Delos. But Orion, eager for revenge against Oenopion, soon left the dawn-goddess and traveled to the island of Chios, where Oenopion lived.

Because he didn't find the king (who had hidden himself in a cave), Orion journeyed on to Crete thinking that Oenopion had taken refuge with his grandfather, King Minos. On Crete, Orion encountered Artemis, goddess of the Moon, who was just as keen a hunter as he was. In Orion, Artemis (renowned as an icily-beautiful deity) had finally found someone worthy of falling in love with. Abandoning his vengeance-quest, Orion gave himself up to the delights of hunting with Artemis — and soon their affair attracted notice.

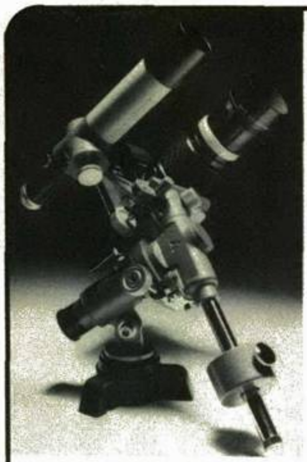
Artemis' brother was Apollo, charioteer for the Sun. He saw that Artemis was so smitten with Orion that she was neglecting her duties and had let weeks pass without once carrying the Moon across the sky. Arguing with her got him nowhere, so Apollo concocted a plan to get rid of Orion.

One day when Artemis was away, Apollo spoke to the Earth goddess, who sent a gigantic scorpion from out of the ground to challenge Orion. By this time Orion was extremely vain of his hunting skills and delightedly agreed to fight the scorpion. Back and forth the battle raged, yet neither was able to deliver a decisive blow. Unfortunately Orion was merely mortal and eventually grew tired, while the creature came on and on. Finally Orion had to run for his life. He raced to the shore, dove in, and began to swim powerfully out to sea. Soon he was only a distant speck, bobbing amid the wave tops.

At this point the second half of Apollo's plan began to unfold. Calling his sister's attention to the unrecognizable black dot far away, he tauntingly told her that although she was good with her bow, even she had her limits, and it was unlikely that she could hit the little target.

Stung to the quick, Artemis promptly fitted an arrow to her silver bow, drew to full reach, and sent the arrow humming. Her aim was perfect. Pierced through the head, Orion died instantly. When his body washed up on shore, Artemis, horrified to discover what she had done, wept and wept. Hastily taking the body to Aesclepius the doctor, she begged him to restore Orion to life. Before Aesclepius could perform the miracle, however, a thunderbolt from Zeus destroyed him. Accepting at last that Orion was irretrievably gone, the heart-broken goddess set her lover among the stars.

But not just anywhere in the sky. In bitter tribute to the creature that started the fateful chain of events, Artemis carefully placed Orion in the winter sky — where half the heavens lay between him and his nemesis, the Scorpion.



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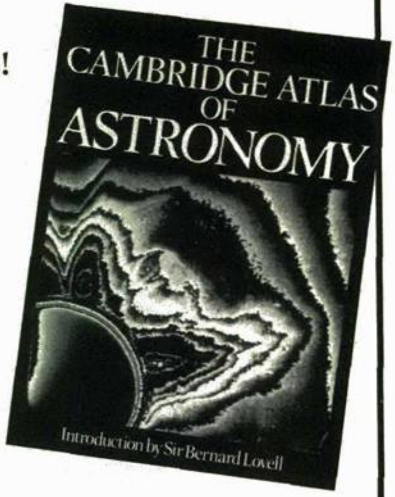
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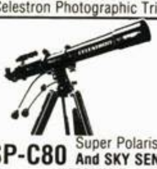

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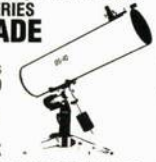

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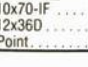

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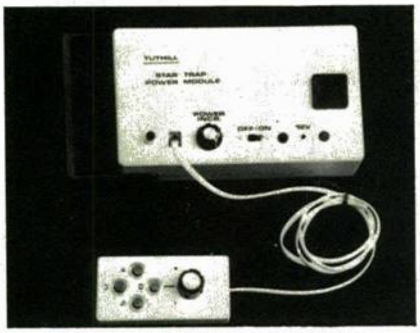

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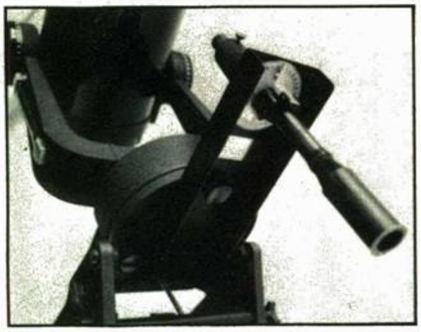
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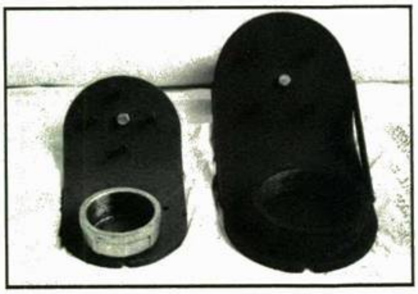
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How I Built a Real Live Telescope

by Edgar Doleman

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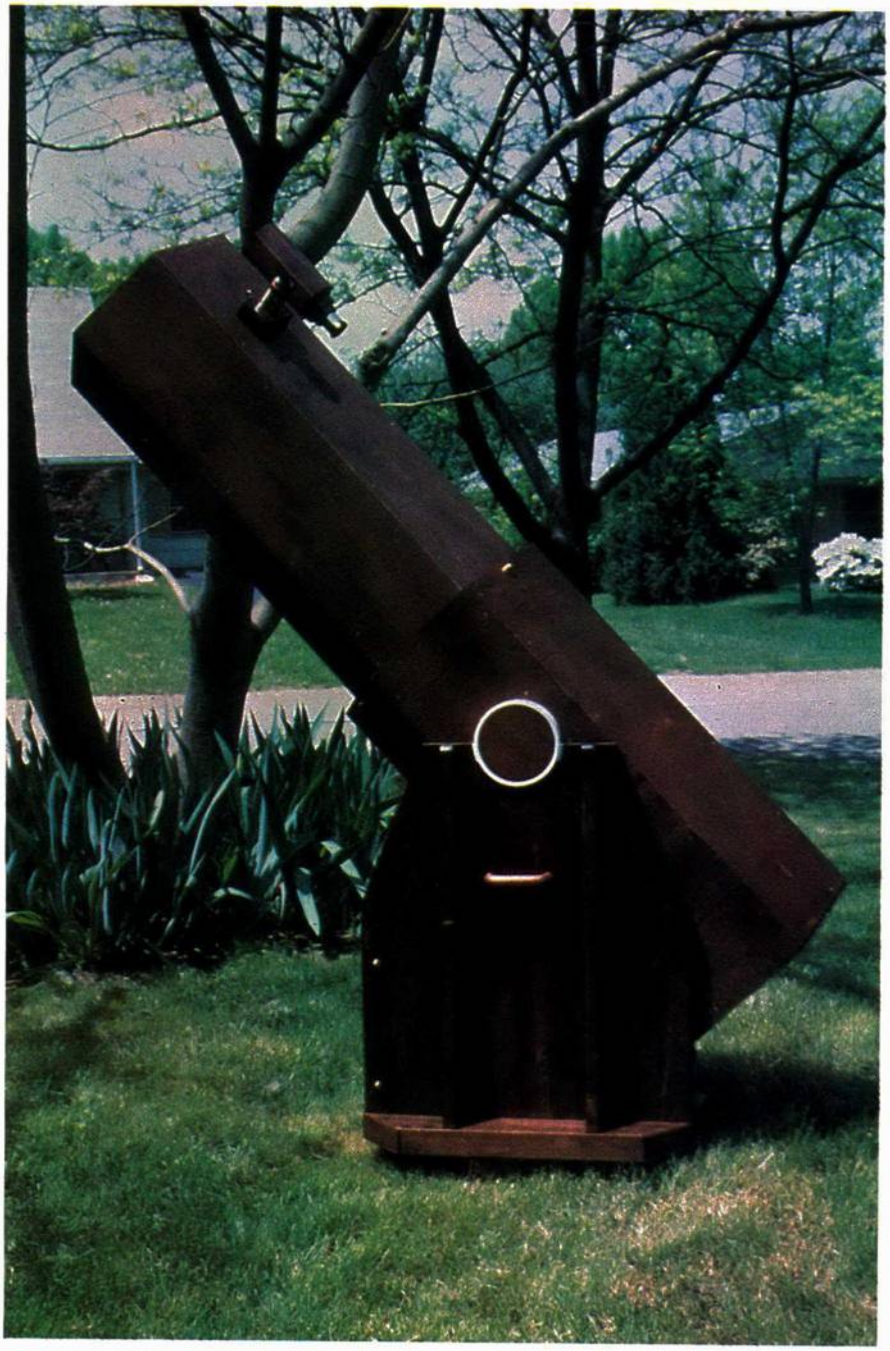


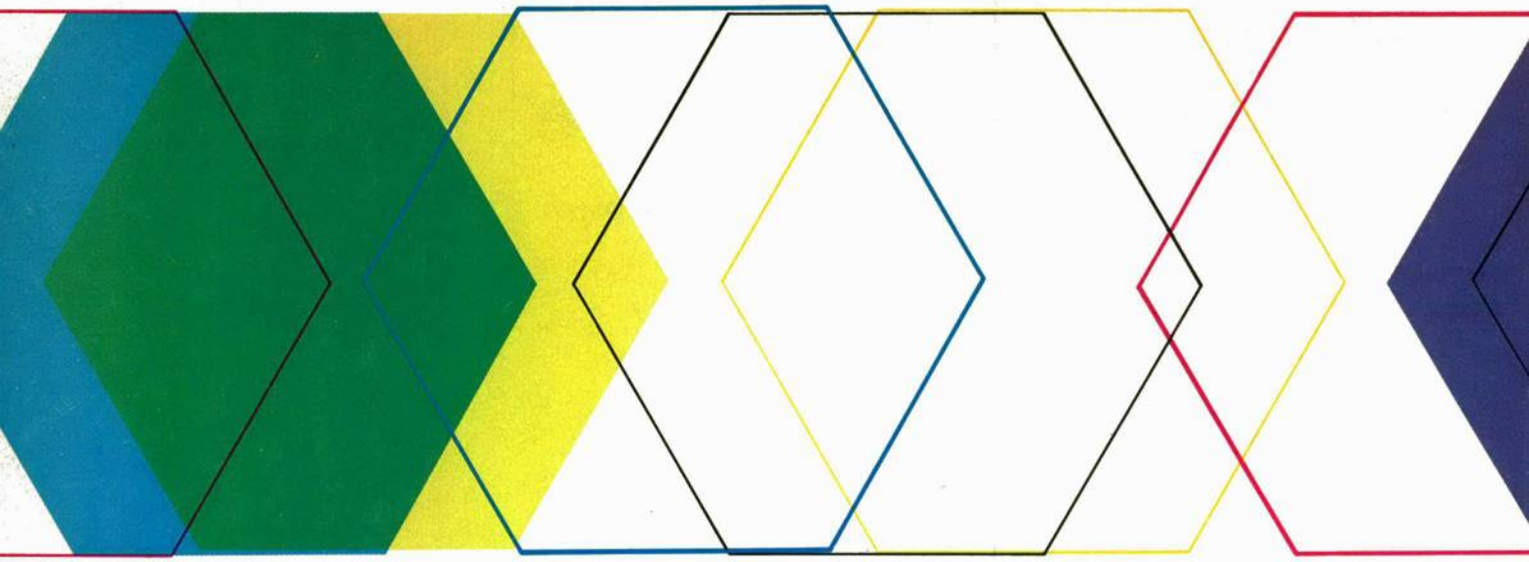
For half a lifetime I wanted a good telescope. Long ago during my teens I did own one, a tiny refractor with an altazimuth mount about as steady as a drunk on a Saturday night. Girls down the block looked great. I could map the Moon, make out the Galilean moons, and almost convince myself I saw Saturn's rings. Alas, one night a fatal accident claimed my precious little refractor. It fell out of a window.

Sometime more recently I dreamed of experiencing the wonders of the heavens again. I fell in love with the idea of having an expensive catadioptric instrument but didn't want to part with a great amount of money. I just wasn't very upscale with my hobbies.

Ever so slowly the crazy notion of building a telescope crept into my mind. My dreams would be fulfilled at a cheap price; I ground a dozen mirrors in my imagination. But there were always reasons not to start one in reality. I didn't have a basement or garage. I was about to move. I couldn't understand Foucault's test. I ordered a "classic" book on telescope making from which I learned that home telescopes are complex and massive things built by people who wear ties and unpressed pants and must be machinists by trade.

One day I read an article about a Dobsonian telescope that the author implied even an idiot could build. I qualified. In the same magazine a 10-inch mirror was advertised at $129. Ten

How can you build a 10-inch Dobsonian telescope with a telescoping hexagonal tube for under $300 — without telescope-making experience? It takes a healthy dose of ingenuity. Photo by Edgar Doleman.



incredible, affordable inches! I was enthralled.

But I was also cautious. You see, I've read countless articles on amazing creations that somebody has put his last six months into. Some read like a math teacher's attempt at obfuscating calculus, some like a master carpenter trying to make wainscotting sound simple. Because of the pride and seriousness of these authors, I knew they weren't talking to me. Bragging is a human trait. I was positively shameless after my last noteworthy achievement — learning to tie my shoes — and for a long time I refused to tie them at all without someone to witness my precocious dexterity.

Seeing braggadocio disguised with modesty in writing didn't encourage me — it was flat intimidating. Yet the idea of having a 10-inch telescope for the price of a weekend vacation held an ineluctable appeal.

"Act, or spend a lifetime with your nose flattened against the candy store window," I told myself. Did I succeed? Yes, wonderfully so — even with the mistakes.

I had ASTRONOMY's articles on how to build a Dobsonian (appearing in the June, July, and August 1980 issues) and to hedge my bet I squandered $4.50 on a reprint of similar articles from *Telescope Making*. This time I didn't just look at the pictures but actually read the words, learning esoteric terms like "rocker box" and "closet flange." A spider could be made out of rough laths. The tube was a cheap piece of cardboard called Sonotube, and need be only 60 inches long for a 10-inch mirror. The whole thing turned on a Formica sink cutout. How simple it all was!

Soon I'd be tossing a 10-inch marvel into my trusty Toyota and — but wait! Would something 60 inches long and a foot in diameter fit? It would, but not with passengers. Although my kids would fit neatly in the trunk, they quite unreasonably refused to ride in it. It seemed that the telescope would either fit in the trunk or I would travel alone.

I ground a dozen mirrors in my imagination. But there were always reasons not to start one in reality.

So I couldn't just slavishly follow the instructions and blame any failure on the author. I had to design my own telescope, and finally settled on three criteria. The telescope had to fit in the trunk of a 1976 Toyota Corolla because two children and a mother had to ride inside. I wanted enough aperture to see faint objects; preferably about 10 inches or so. And it could not look too offensive. Rough cut laths and cardboard may be functional, but they're hardly aesthetic. Although it would be used in the dark, it would necessarily spend its days as a rather prominent indoor object.

How could I reduce the length of the tube? I somehow needed a telescope that disassembled and a tube that squashed from 60 inches into 40 inches so it could fit in my trunk. How? Everything I had ever made wobbled. I could think of no reasonable way to fabricate a collapsing tube from Sonotube. And I didn't want to face the messy business of getting the waxy coating off anyway. So, for a mere $15 I got a sheet of ¼-inch plywood and for $5 more a couple of feet of poplar, a wood often used for parts of furniture you don't see.

I would make two hexagonal telescoping tubes with poplar frames and a skin of plywood all glued and screwed together. My investment passed $30, but now I was telling myself that if it's worth doing, it's worth doing right.

No matter how carefully I measured and cut, I could not make a perfect hexagonal frame. Each side ended up with its own unique dimensions. Eventually, like puzzle pieces, I got them to fit together.

Five-inch closet flanges were the recommended tube bearings. What these might be was a mystery until a hardware clerk advised that in this case a closet is a "water closet," or toilet. A closet flange is a squat piece of flanged pipe connecting the toilet to the pipe it flushes into.

Obviously I wanted new, not used, closet flanges. They were not very aesthetically pleasing so I bolted them to the inside of the tube to hide the flange and filled the resulting hole with a plywood cutout. The tube began to look like a short, hexagonal cannon with white plastic trunnions.

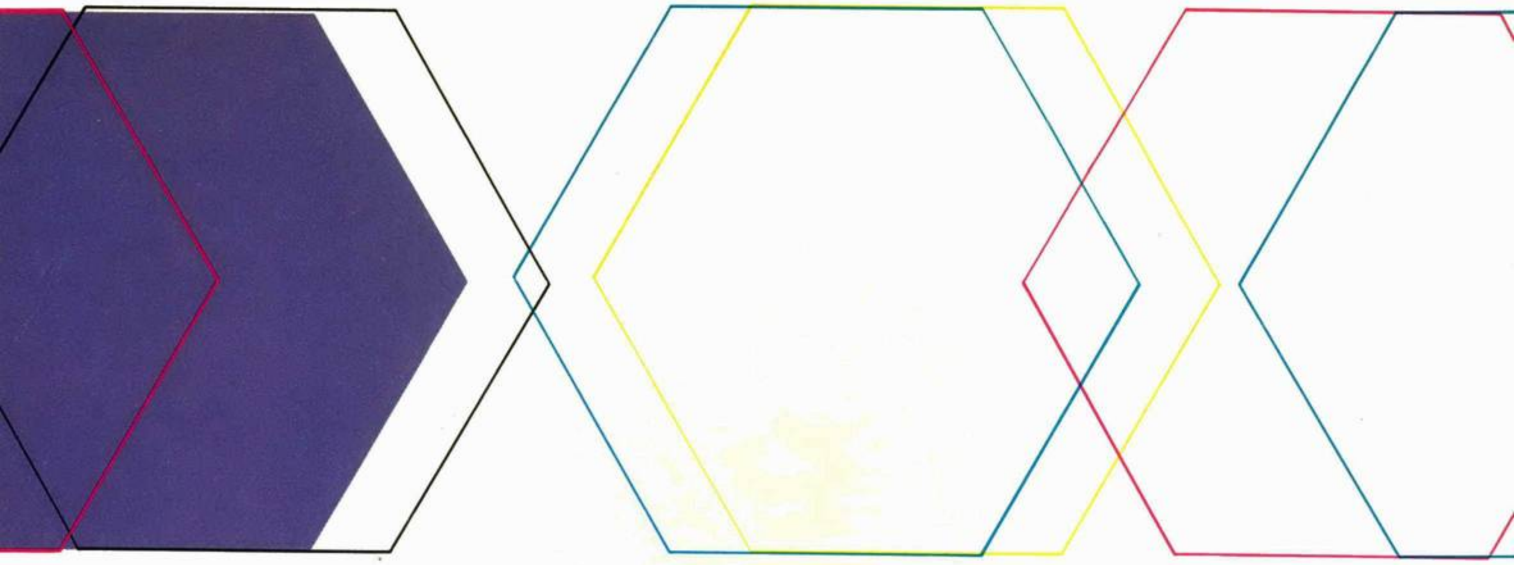
'Act, or spend a lifetime with your nose flattened against the candy store window,' I told myself.

I did most of this work at a woodshop shared with a number of expert woodworkers. Whistling and chatting, they moved confidently among ripsaws, planers, joiners, routers, sanders, and forests of clamps. Not me. I muttered "Oooops!" a lot. Naturally they were curious about the odd, polyhedral contraption taking shape around me and sooner or later each approached and asked, "Whatcha making?"

"A telescope," I'd say. Nothing *common* like a bow-front dresser for me!

Invariably they stared slack-mouthed a moment and then asked with genuine puzzlement, "Why?"

"To see the stars." Somehow this reply



never seemed to satisfy.

In spite of the stubborn refusal of rulers and protractors to yield the same measurement twice, of saws to cut true, of drills to bore straight, and of glue to stay off surfaces it didn't belong on, the project took shape.

The inner tube slid neatly within the main tube, guided by rails that were part of the frame. The wood stops that prevented the mirror from flopping forward also stopped the inner tube from slipping out the back. My telescope had six sides so I put in six of these stops (and, of course, anchored the stout plywood mirror cell to all six), but I used three nylon bolts for the actual mirror suspension, as recommended for 10-inch and smaller mirrors.

The spider is a 1-inch dowel and three strips of ⅛-inch basswood in lieu of ugly lath. I added front and end caps partly to keep out dust and cats while the telescope was doing duty as a prominent indoor object, and partly for appearance.

Four pretty brass bolts lock the tube in its extended position. I sanded it, painted it flat black inside, stained it mahogany, and gave it a polyurethane finish. The result was a hefty tube that, when collapsed, fit into my Toyota's trunk and looked, well, quaint and sort of antique. My mistakes weren't obvious.

There are some fine points I must keep in mind when transporting and using the scope. Every time I assemble my telescope I must realign the mirror — a five- to ten-minute chore.

I built the front half of the tube as stoutly as the rear half. This superfluous strength moved the center of gravity well forward, necessitating a taller rocker box to handle the swing of the aft end. One can be too compulsive about strength, you know.

The "how-to" articles were not too clear on the point of just where the prime focus should be, only that it should be outside the tube. As far as I could tell, an inch or so outside the tube was fine. Various errors conspired to make it a generous two inches, so the mistake wasn't fatal. But it was a good thing I didn't invest in a commercial focuser. As it is I can't get the film plane of my camera to the focal point and I have to change focuser tubes with eyepieces. Oh, I can fix it — I've just been too busy using the telescope to bother.

I read somewhere that a Dobsonian isn't the telescope of choice if you're a light-polluted urbanite. I'm glad I didn't know that.

I also glossed over the matter of a finder scope. Consider the poor neophyte who, after laboriously building his 10-inch f/5.6 marvel, points it at the night sky hoping to see something through his 15mm eyepiece. He is gazing at a patch of sky barely half a degree wide, filled with star patterns bearing no resemblance at all to his chart. He is aiming it with all the finesse of the Civil War cannon it faintly resembles and expecting to hit a sharpshooter's target. Will he? No.

Fortunately, when the kindly dealer who sold me my eyepiece heard my woe, he gave me a 50mm objective and an eyepiece from an old pair of binoculars. This finder scope became an interesting project that taught me several things.

First, a finder scope really needs crosshairs. They are easily made from your wife's or son's or daughter's hair. Second, you can align the two telescopes in your backyard by drawing a chart with two aiming points the exact separation and orientation of the main and finder scopes. I couldn't put a ring mount on my tube and still fit it in the trunk, so I used a brass flange. The finder scope mounts with a single bolt that draws it against both faces of the flange, resting on four set screws. Adjusting these changes its alignment with the telescope.

I didn't even think about the rocker box until after I had built the tube. The how-to articles stressed the importance of its rigidity, but no rocker box for a 10-inch telescope was going to fit whole into a Toyota trunk. I found dozens of Dobsonian mounts illustrated but none purported to disassemble. Petrified, I just blocked it from my mind and built the tube.

Inevitably, the day came when I had a tube and nothing to rock it with. I invested $35 in a sheet of ¾-inch furniture-grade plywood and, thus committed, began to design a rocker box. The side boards got extra rigidity from two stout vertical ribs glued and screwed fast. The baseboard was screwed and glued to the sink cutout. I learned how to use a router and routed grooves so that the front board fit into grooves in the side boards and all three fit into grooves in the base. I set hanger bolts, screws on one end and bolts on the other, into the mating ends of the side and front boards so that when the whole mess is fitted together, they can be bolted down tightly.

Confidently I turned to the base, the thing the rocker box would turn on, and realized to my horror that the triangular shape of my design would be unstable. I had considered only the distance from the axis to the points of the triangle, not the much shorter distance to the sides. With its considerable weight and high center of gravity it would tip easily.

But I wasn't about to give up yet. I drew triangles all over the remaining plywood. After much trial I cut out one large and six small triangles, and fitted them together with gobs of glue and a rat's nest of clamps. The result was a hexagonal base 1½ inches thick. This base sits on six little feet that screw in and out to adjust to the ground's contours.

To my surprise, relief, and amazement, the whole thing is rigid as can be and yet disassembles to share the Toyota trunk with the tube. There is even room left over

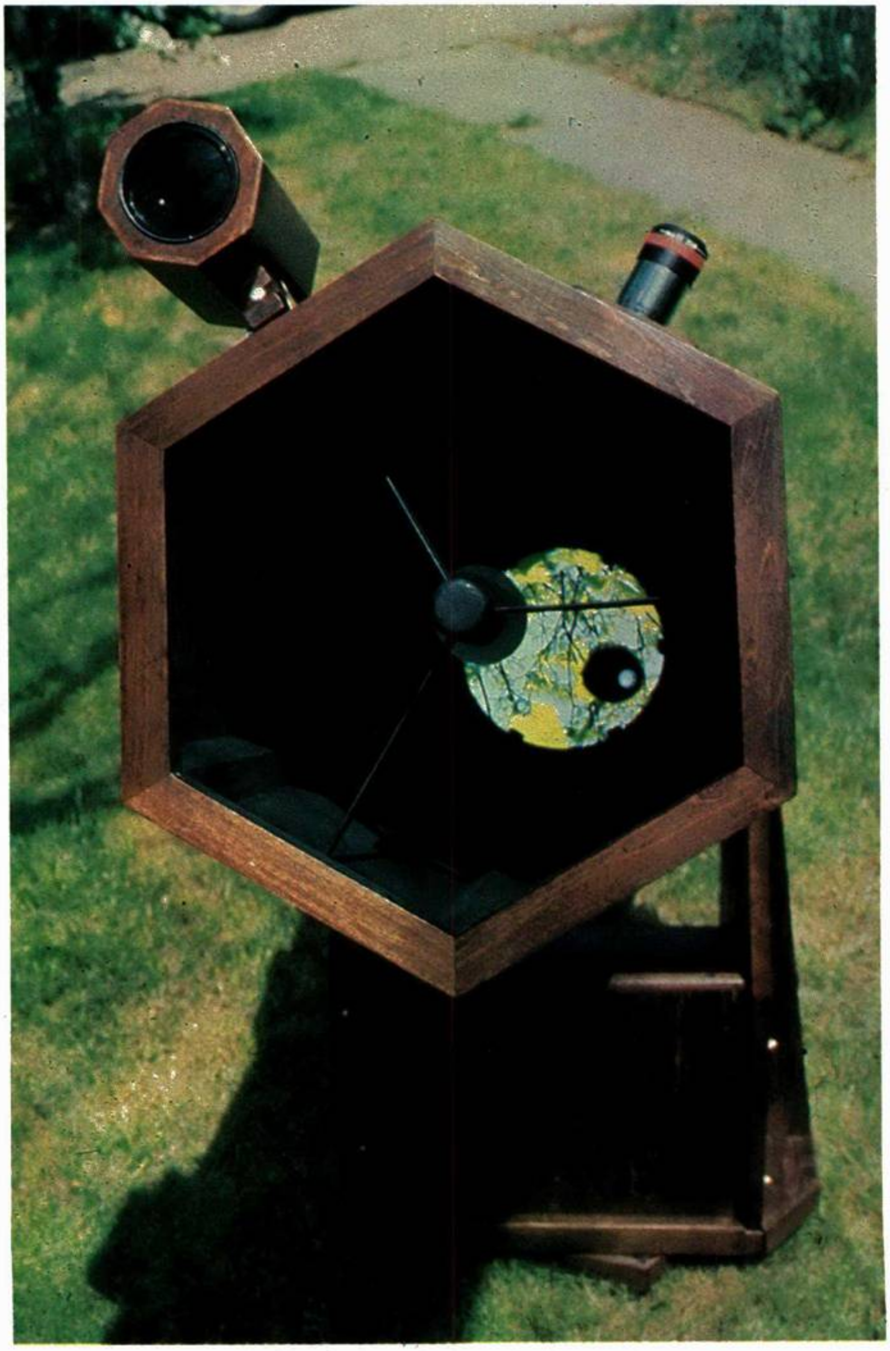
A view down the telescope's tube shows the author's 10-inch primary mirror, hexagonal tube structure, four-vaned spider, and finder scope. Photo by Edgar Doleman.

for, say, a toothbrush.

What about the telescope's bearings? Well, Teflon isn't just good for pans; it also works great on telescope bearings. It was easy to get but expensive, costing some $14 per square foot. It makes the scope operate with ease. When I push, it moves — smooth as silk. When I stop, it stops — dead.

By some miracle I had correctly calculated the center of gravity when cutting the holes to hide the closet flanges. The tube was perfectly balanced until I bolted on the finder scope; then it took a nose dive. But balance was restored with an old barbell weight attached to the rear cover.

I read somewhere that a Dobsonian is not the telescope of choice if you're a light-polluted urbanite. I'm glad I didn't know that. If I had, I would not have decided to see which "right" telescope I could get for under $300, and I would have done nothing. Near the city 10 inches of mirror gathers more indigo sky than stars, but it's much better than not observing at all. And when my 75 pounds of mahogany-hued cannon is stuffed into my Toyota and trundled out into the dark country, well, it makes up for it.



Retired from the Army, Edgar Doleman is science writer and author of the book The Tools of War, *part of the Time-Life library on the Vietnam War. His astronomical interests include astrophotography and deep-sky observing.*

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ASTRONOMY
Reviews

Sun and Earth
Herbert Friedman
251 pages, cloth, $27.95
W. H. Freeman (1986)

The beautiful image on this book's dust jacket, a detail from a painting by the French impressionist Monet, sets the tone for this richly illustrated and superbly written volume by one of the world's leading space physicists. In the tradition of *Scientific American*, the sponsoring magazine, *Sun and Earth* is entertaining and stimulating for both scientists and laymen.

Addressing a topic often relegated to a few paragraphs in most astronomy texts, the book begins with a history of solar astronomy that includes general discussions on spectroscopy and electromagnetic radiation. Particular attention is paid to the interaction of solar radiation with Earth's atmosphere.

The second chapter discusses solar structure and energy sources, covering such current topics as solar neutrinos, supergranules, and acoustic vibrations. The highlight of this chapter is a spectacular color illustration depicting the architecture of the Sun and clearly showing the major features of its various components.

The next chapter is devoted to the solar atmosphere and magnetosphere and introduces the sunspot cycle. After he outlines what is clearly known about the Sun, the author finally turns to the Sun's interactions with Earth. Two chapters are devoted to the effects of solar electromagnetic radiation and the solar wind on our planet and its magnetosphere. The following chapter discusses how these phenomena relate to weather and climate. The concluding chapter is a provocative collection of inferences and speculations about the origins and endings of the solar system.

In *Sun and Earth* Friedman does an outstanding job of covering an important and extensive scientific topic in a very readable and enjoyable narrative style, which is complemented by numerous illustrations that are both clarifying and pleasing. This book is a pleasure to read and is highly recommended for both novices and professionals. *David Jourdan.*

The Discovery of the World
Elizabeth Hale, ed.
87 pages, cloth, $60
University of Chicago Press (1986)

This book contains facsimile reproductions of sixty early maps of Earth, five early maps of the sky, and one early Moon map, (twenty-four of which are in color), and provides commentary on how they were created. The star maps are those made by Nicholas Sanson d'Abbeville (1658), Cellarius (circa 1660), Pieter Schenk and Gerald Valk (1706), and Georg Christophe Eimmart (circa 1705). The Moon map was made by Nicholas Bion in 1728.

The Bedford Catalogue
William H. Smyth
560 pages, paper, $19.95
Willmann-Bell (1986)
[Publisher's address: Box 35025,
Richmond, VA 23235]

Admiral Smyth's *A Cycle of Celestial Objects*, published in 1844, is far better known from scattered quotes in modern observing manuals than from personal acquaintance, which is a shame. While the nineteenth century witnessed the completion of many observer's guides to astronomy, few of today's telescope owners have ever seen them (with the outstanding exception of T. W. Webb's *Celestial Objects for Common Telescopes*, which Dover Publications has kept in print for many years).

Observers who haunt large libraries and second-hand bookshops may have seen Thomas Dick's *The Practical Astronomer* or George F. Chambers' massive *Handbook of Descriptive and Practical Astronomy* (which even contains fold-out plans for an observatory and dome), but the Holy Grail for astronomical booksnoopers is Admiral Smyth's famed work.

William Henry Smyth (1788-1865) lived in a period that began with William Herschel's most productive years and saw the introduction of the spectroscope. Smyth's father was a loyalist American who had left New Jersey following the Revolution; his son William Henry was born in England. Smyth joined the Royal Navy when he was young and commanded a brig in the Mediterranean during the recurring wars against Napoleon.

While on active duty he visited the Palermo Observatory and met its director, Guiseppe Piazzi, who had discovered Ceres, the first minor planet, twelve years earlier. Smyth was fired with enthusiasm for astronomy, and upon retiring from the Navy in 1825, built a private observatory in Bedford, a town about forty-five miles north of London.

His main instrument was a 5.9-inch f/17 refractor made by Charles Tulley. The telescope was a large instrument in its day. It was carried on a two-pier "English" equatorial mounting, which had setting circles three feet across. Smyth always claimed the instrument was Tulley's best work, and many professional astronomers were impressed by the clean, sharp, color-free images it rendered.

Measuring stellar parallaxes and the separations of double stars was at the forefront of astronomical research in the 1830s and 1840s. True to the times, Smyth concentrated on observing multiple-star systems. In fact, of the 850 objects he chose to include in his *Bedford Catalogue*, only 170 are *not* double or multiple stars.

In 1844 Smyth's great opus *A Cycle of Celestial Objects* was published in two volumes. The first volume contained a survey of astronomy, a description of his observatory and telescopes in general, and a summary of objects in the solar system, (which naturally stopped at Uranus, because the discovery of Neptune lay two years in the future). The second volume, covering objects outside the solar system, was titled *The Bedford Catalogue*. The year after the book was published, the Royal Astronomical Society awarded Smyth its gold medal and promptly elected him president. This second volume is what Wilmann-Bell has reprinted.

Now it's only fair to ask if there is any point in re-issuing a scientific work first published when Abraham Lincoln was just another Illinois lawyer, when the United States ended at roughly the 90th meridian, and when much of the West belonged to Mexico? The answer, surprisingly, is yes.

On one hand, the scientific value of Smyth's observations has long since waned. He was somewhat careless in his position and separation measurements, and the words he used to describe star colors (always questionable when seen with a refractor) may strike us as imprecise or unnecessarily florid today.

Sensitive to these criticisms, Smyth published a glossary in later years which recast his old color names in more straightforward terms. For instance, "fawn-colored" really meant "whitey-brown," "sardonyx" was actually "reddish yellow," and "amethyst" was "purple." (But in 1981 the astronomer Paul Murdin showed that the old, often-disparaged color estimates actually came close to modern B-V photometric colors, with difficulties only in the red and blue-white ends of the spectrum. So who's to say?)

On the other hand, I hope no one is foolish enough to look for up-to-date information in *The Bedford Catalogue*. The book's main value lies in its antiquarian interest and delightfully expansive style. This is evident in its description of globular cluster M-3: "With its stragglers, it has something of the figure of the luminous oceanic creature called *Medusa pellucens* . . . this mass is one of those balls of compact and wedged stars, whose laws of aggregation it is so impossible to assign."

And Smyth describes M-57 with the following statement: "If the oft-cited cannon-ball, flying with the uniform velocity of 500 miles an hour, would require millions of years to reach Sirius, what an incomprehensible time it would require to pass so overwhelming an interval as 950 times the distance!" Anyone deaf to the charms of this sort of thing should turn in his telescope and eyepieces.

It's precisely for these leisurely descriptions — and for his transparent, irrepressible joy in observing the heavens — that Smyth earned his reputation as the most widely-quoted astronomical author. Many a later astronomical writer, stuck for a way to express what he sees in the eyepiece, has turned to the appropriate section of Smyth. Often the old Admiral is right on target.

I recommend this book unhesitatingly. It isn't all of Smyth's classic opus (I'd love a reprint of Volume 1), but it's much more of it than I had before. And, given the prices that copies of the original edition fetch on the used book market, it's all that I'm likely to have for a long time. *Robert Burnham.*

Cosmology: The Search
for the Order of the Universe
Charles J. Caes
174 pages, paper, $10.95
TAB Books (1986)

Cosmology is an introduction to astronomy that includes some history, some astrophysics, and a section entitled "Speculations" that discusses such topics as UFOs and life on other worlds.

European/United States Space Activities
Peter M. Bainum and Friedrich von Bun, eds.
430 pages, paper, no price given
American Astronautical Society (1986)

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conference held in March 1985 at NASA's Goddard Space Flight Center and is the sixty-first in a series published by the American Astronautical Society. It covers space activities of concern to Europe and the United States. A special supplement on space propulsion for the 1990s is included.

Communications Satellites
Larry Van Horn
255 pages, paper, $16.45
Grove Enterprises (1986)
[Publisher's address: P.O. Box 98, Brasstown, NC 28902]

Communications Satellites is a guidebook listing countries of origin, frequencies, downlink information, and other facts about communications satellites for those who wish to monitor transmissions.

Space Exploitation and Utilization
Gayle L. May, *et al.*, eds.
724 pages, paper, no price given
American Astronautical Society (1986)

This is the proceedings volume from a symposium held by the American Astronautical Society and the Japanese Rocket Society in Honolulu in December 1985. Included are semitechnical papers and addresses about the future of man in space.

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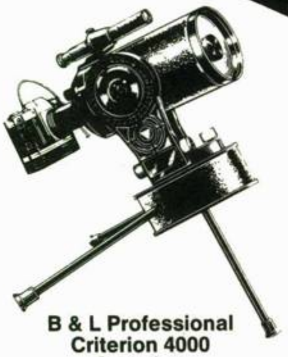

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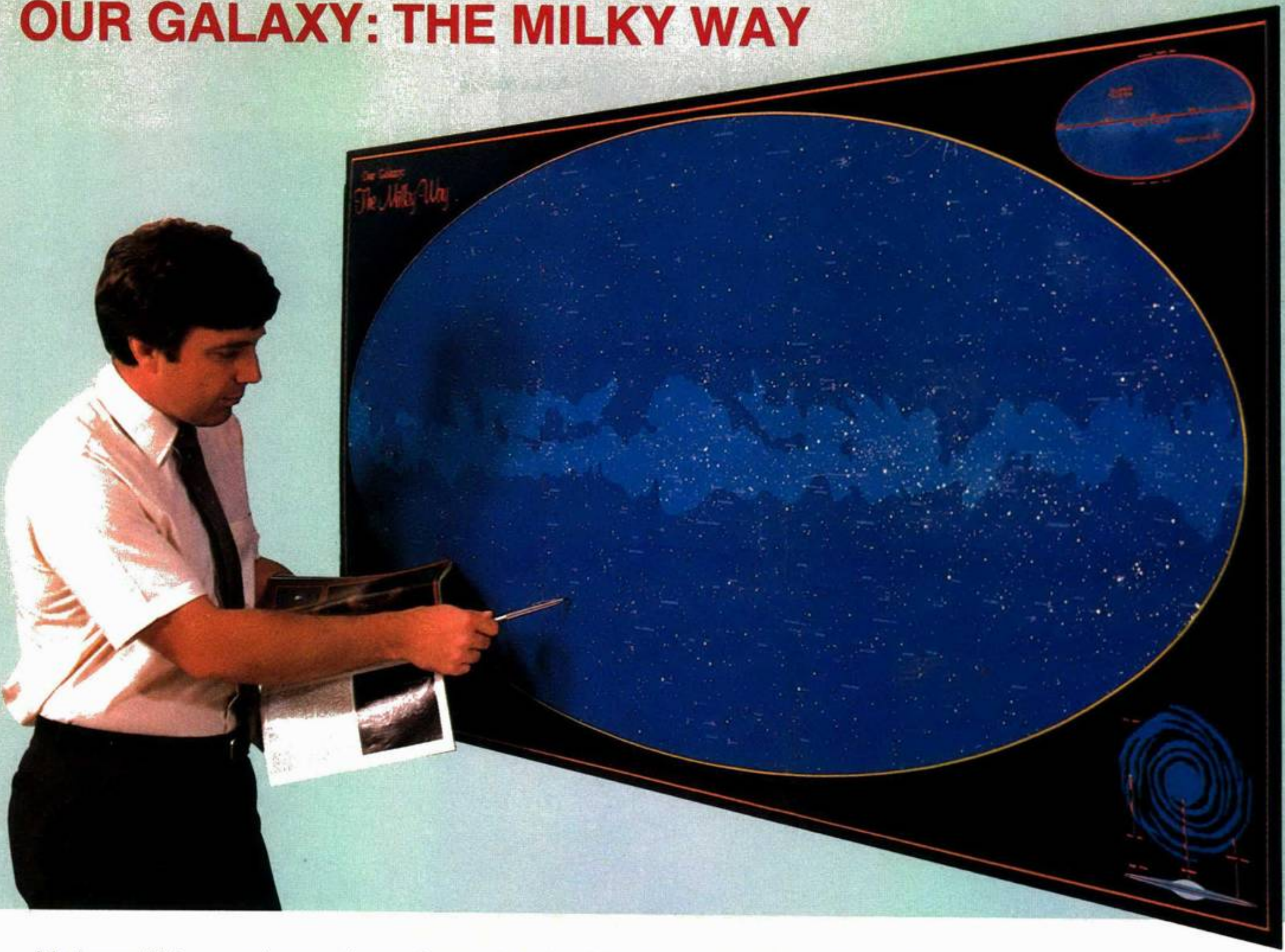

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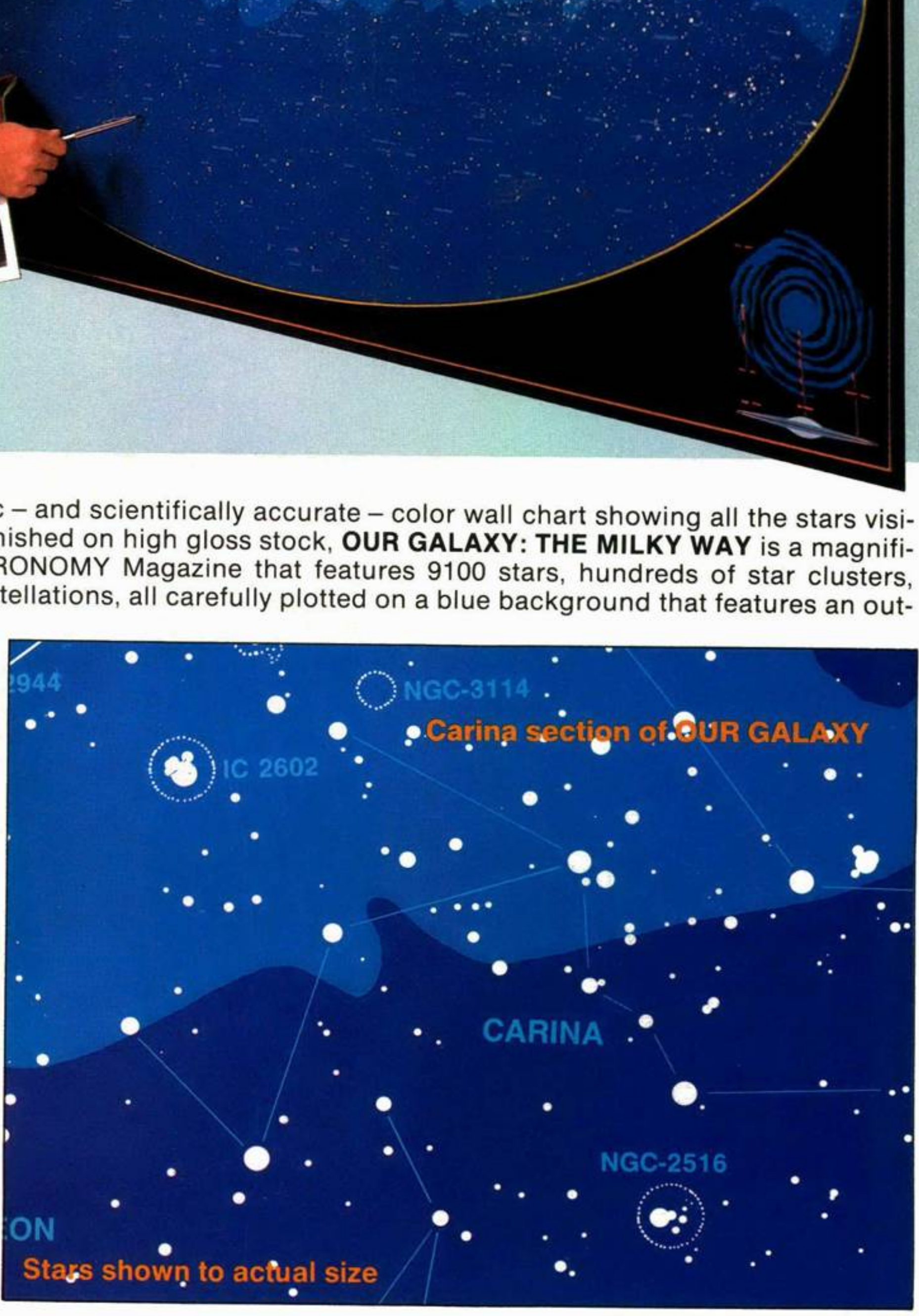

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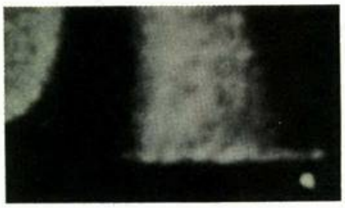

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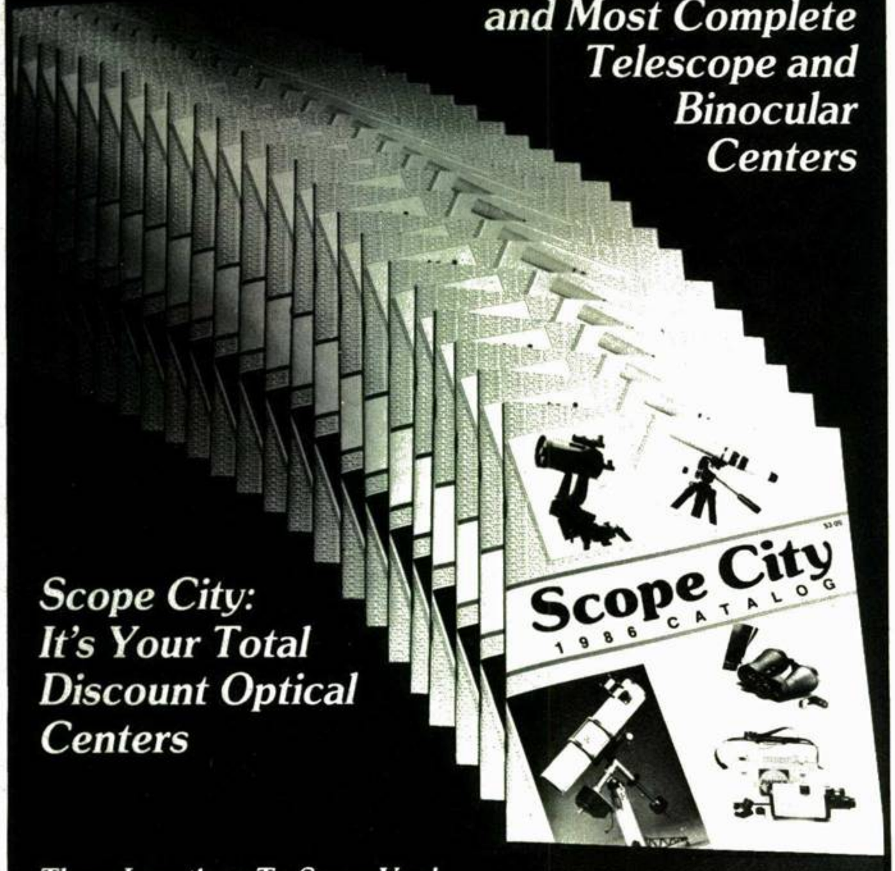

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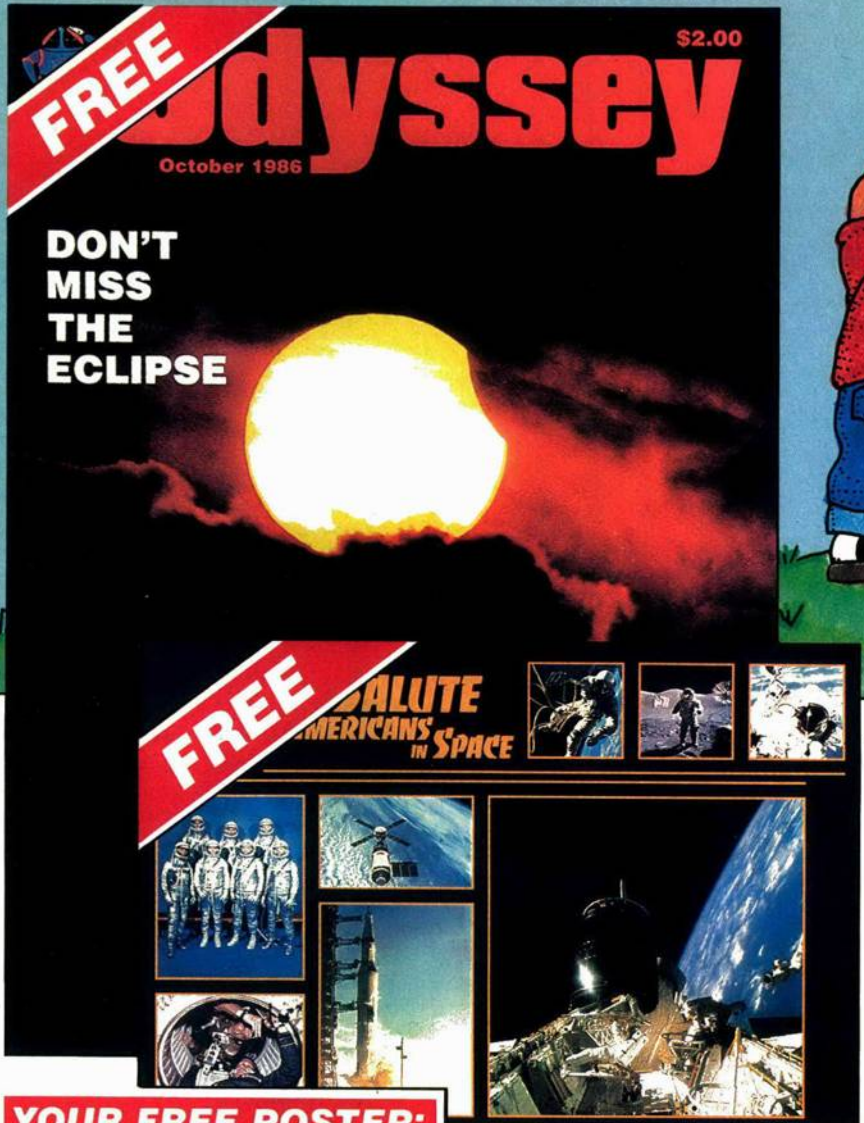

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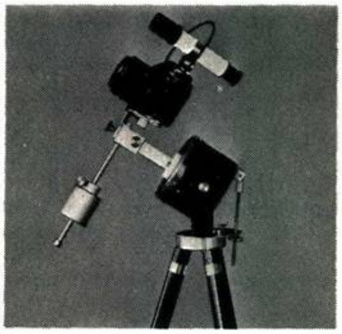

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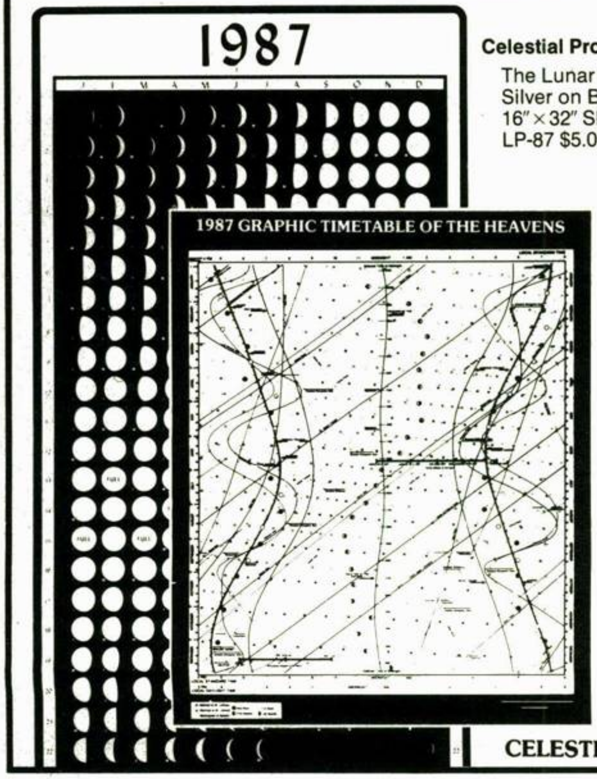
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by Guy Ottewell

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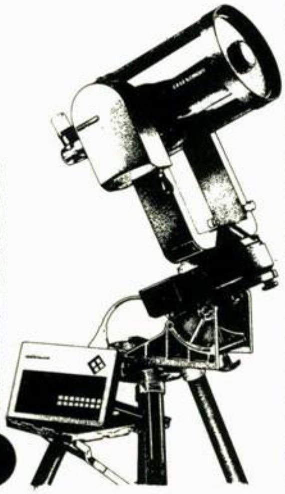

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Observing the Elusive Comet Wilson

by Alan Hale

A Comet Wilson Chronology

August 5, 1986 — Christine Wilson discovers a new comet
January 21, 1987 — Conjunction with the Sun
April 20 — Perihelion (1.2 AU from the Sun)
April 26 — Passes just south of the Small Magellanic Cloud
May 2 — Closest approach to Earth (0.62 AU)
May 2 — Skirts the southern edge of the Large Magellanic Cloud
May 11-25 — Traverses the Milky Way in Puppis
Late May-early June — Best observing period for the Northern Hemisphere

No sooner had the Halley hoopla abated than a graduate student at Caltech, Christine Wilson, discovered a new comet that is expected to brighten to near Halley's magnitude. Like Halley, Comet Wilson (1986l) will follow a southerly track across the sky, thereby reserving its best show for Southern Hemisphere observers. Observers in the Northern Hemisphere will have a few good opportunities to see the comet, but it will not be visible to them at its brightest or during the most interesting conjunctions.

However, Comet Wilson is dramatically different from Halley in one respect: Wilson will be approaching the Sun for the first time. The behavior of new comets is difficult to predict, though. One need only remember back thirteen years to Comet Kohoutek, which was projected to reach magnitude −12 and barely made it to naked-eye visibility. Similarly, no one can be certain how Comet Wilson will behave — it could be significantly brighter or fainter than predicted.

Seeing Comet Wilson will take a fair amount of effort for Northern Hemisphere observers. Because it is not expected to be a bright naked-eye object, you will need to know its precise location, use a pair of binoculars or a telescope, and observe on a night when the Moon is out of the sky. The map on the following two pages shows the comet's position every five days through January 1988. During the period from April 5 to May 25, 1987 — when the comet's motion across the sky is rapid — its position is plotted every day. All positions are for 0h Universal Time (UT) on the date given.

Although Comet Wilson has been fairly well-placed for Northern Hemisphere observers in 1986, this will not be the case in 1987. The last opportunity for seeing Wilson before solar conjunction is in late December and early January. Just after sunset the comet will lie low in the southwestern sky near the Aquila/Sagittarius border. You will have to get out shortly after sunset to glimpse the 10th-magnitude comet before it drops below the horizon as twilight ends. The waxing Moon, which is new on December 31, and the comet's motion toward the Sun will render Wilson invisible after the first few days of 1987.

Following solar conjunction on January 21, several factors conspire to make seeing the comet from the Northern Hemisphere extremely difficult for several months. First, the comet moves in the same direction as the Sun, so that the separation between them remains fairly small. Second, the Sun is moving north along the ecliptic, causing earlier sunrises each day. But most importantly, the comet is plunging southward, leaving northern observers behind.

These last two effects are working in favor of Southern Hemisphere observers, however. Wilson should be well-placed in the east before sunrise and at least 8th magnitude by the end of February. As the comet continues to brighten it may become visible to the naked eye by the March 29 New Moon.

Comet Wilson's best show will take place during April and May in the Southern Hemisphere. The comet will be circumpolar for many southern observers during this time, reaching a maximum southern declination of −77° on April 29. The comet reaches perihelion on April 20 at a distance of 1.2 astronomical units from the Sun and is at its closest to Earth (0.62 AU) on May 2. A peak magnitude of 4 or 5 is expected at closest approach and, to make things even better, New Moon occurs on April 28.

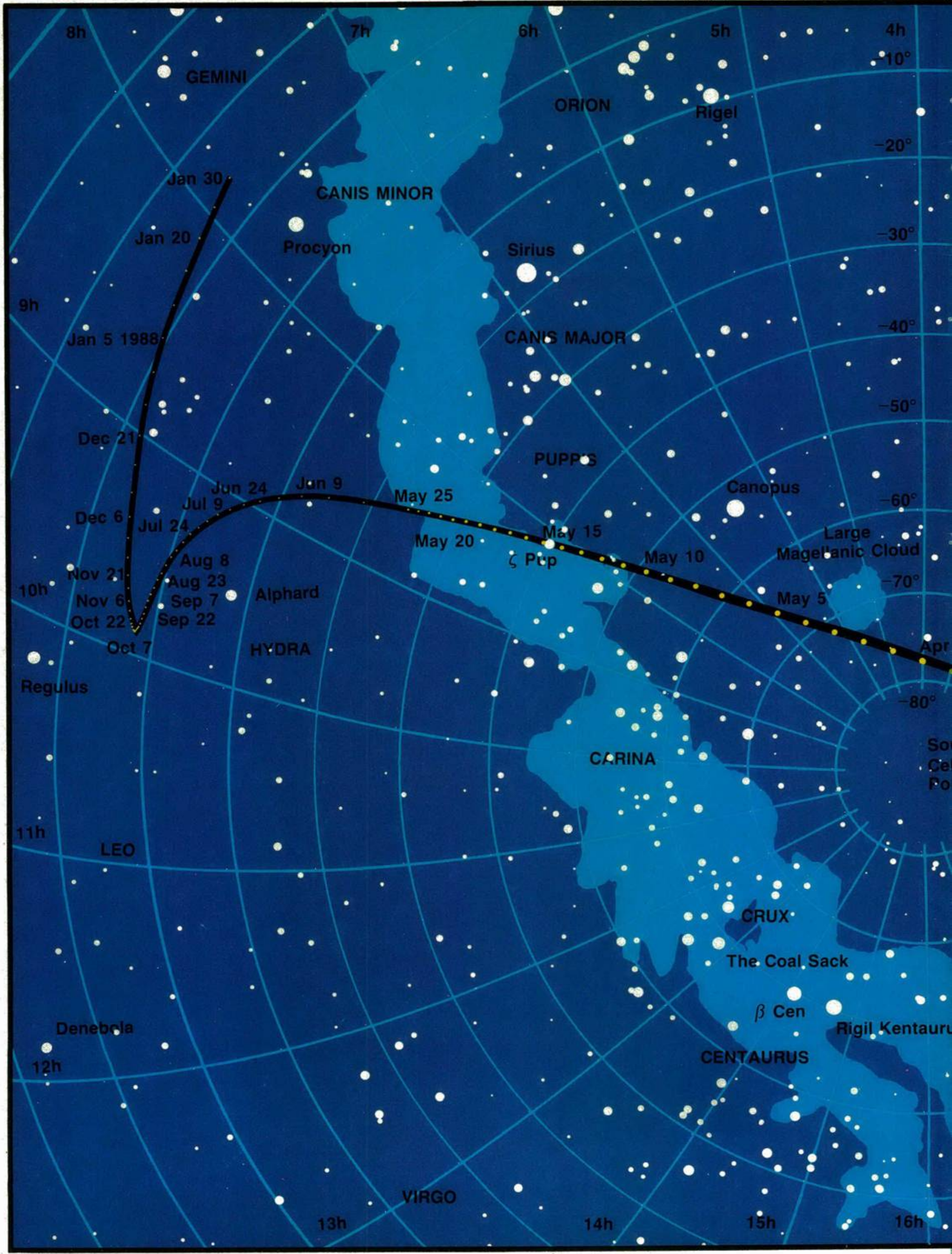
After its closest approach to Earth, Wilson begins a rapid northward movement, and toward the latter part of May it will again become visible from the Northern Hemisphere. The comet passes from Puppis into Pyxis, shining at 5th or 6th magnitude. With New Moon on the 27th, these few weeks will be the best observing window for northerners and their only real chance to see Wilson with the naked eye. The comet will once again be in the evening sky and visible low in the southwest after sunset until the beginning of June.

When the Moon next leaves the sky, Comet Wilson will have dimmed to 7th or 8th magnitude and will be edging ever closer to the Sun. Its elevation decreases steadily as June progresses, and the comet will be difficult to spot after that.

It's unfortunate for northern observers that Comet Wilson poses some of the same visibility problems as Halley did, but for most of us the challenge of seeing a new comet will be worth it. And for the lucky observers in the Southern Hemisphere, the prospects for stunning views and photographs are excellent.

Is Wilson the "Comet of the Decade?" No. But it will nevertheless be welcomed by observers around the world.

Alan Hale is a graduate student in astronomy at New Mexico Sate University. He has been observing comets since 1970 and was the Southwest Visual Coordinator for the International Halley Watch.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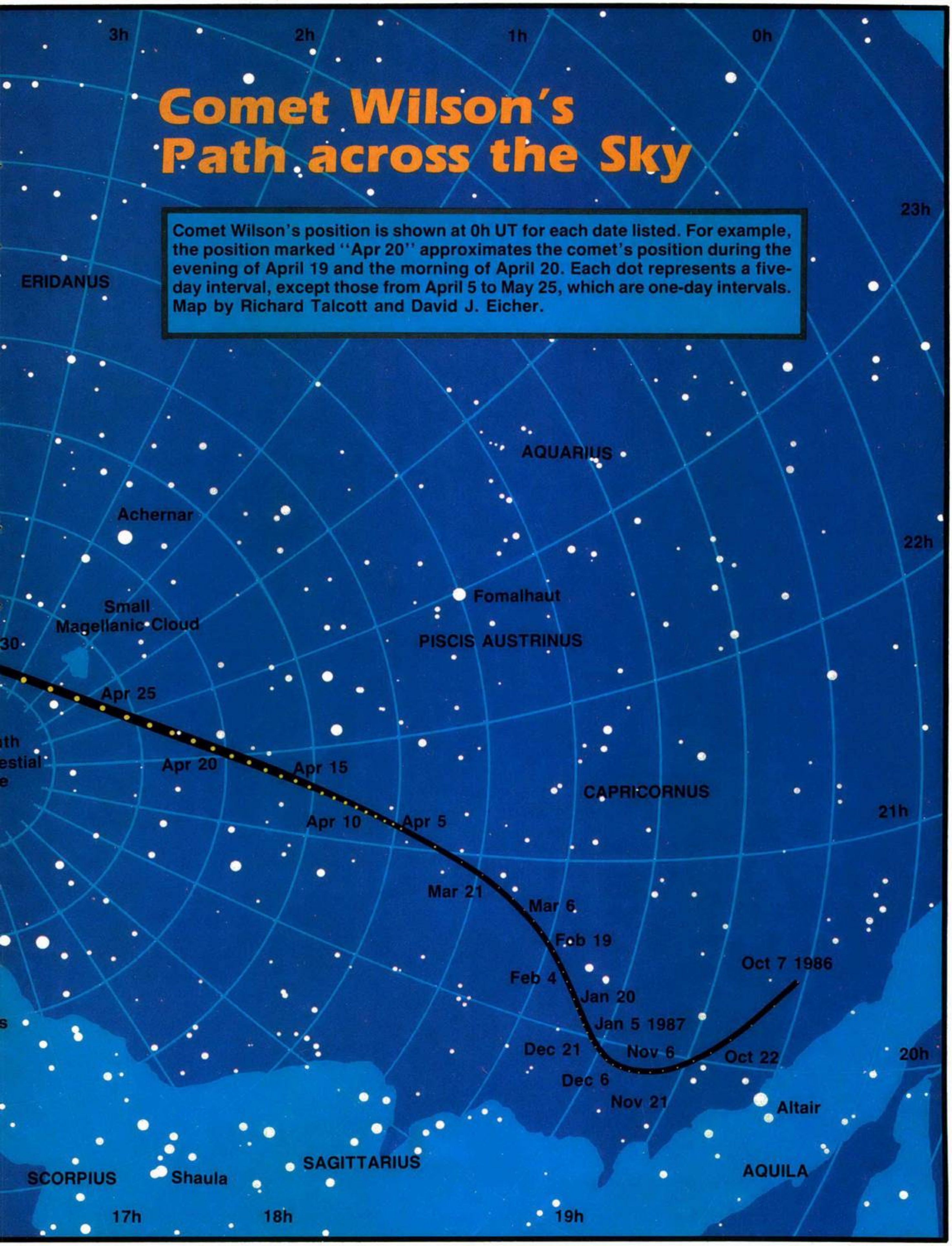
Comet Wilson's Path across the Sky

Comet Wilson's position is shown at 0h UT for each date listed. For example, the position marked "Apr 20" approximates the comet's position during the evening of April 19 and the morning of April 20. Each dot represents a five-day interval, except those from April 5 to May 25, which are one-day intervals. Map by Richard Talcott and David J. Eicher.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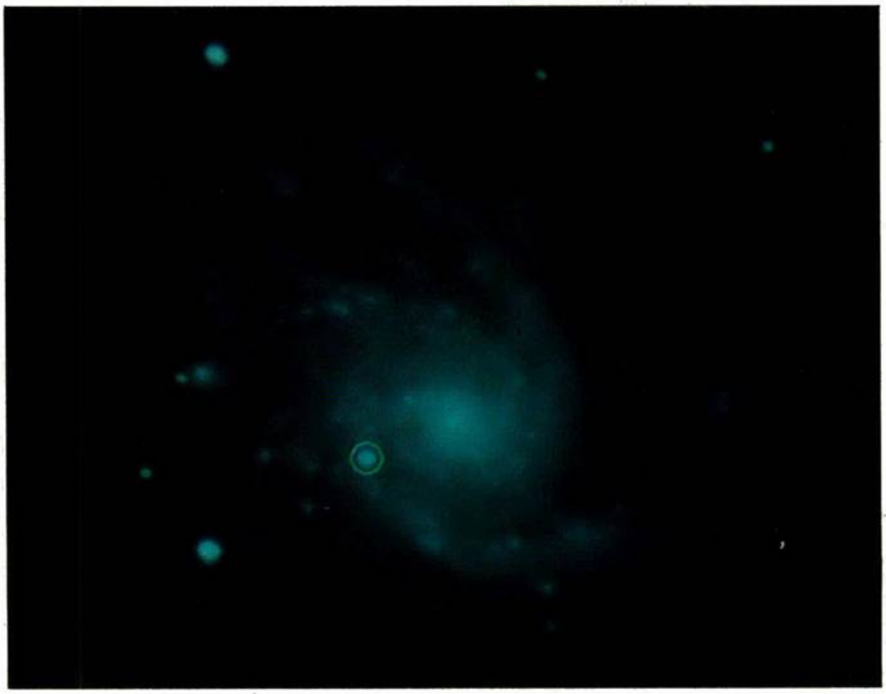

The 14th-magnitude supernova 1986I in the galaxy M-99 was discovered by astronomers from the University of California on May 17, 1986. The supernova was a Type II object whose progenitor star was probably a supergiant with more than 8 solar masses and a diameter of some 10 AU. When the star exploded it shone briefly with about one-fortieth as much light as its entire host galaxy. This photograph was made with a CCD camera attached to the 24-inch telescope on Mount Hopkins, Arizona; the supernova is circled.

This isn't the first supernova in M-99; others have occurred in 1967 and 1972. Photograph courtesy Rudolph Schild, Harvard-Smithsonian Center for Astrophysics.

NASA Assigns Launch Dates to Shuttle Science Missions

Calling it an "equitable balance among the many interests seeking access to space aboard the Shuttle," NASA administrator James Fletcher issued a revised Space Shuttle manifest on October 3, 1986. "In the long run," Fletcher said, "all involved in this process [of designing the manifest], including NASA, believe it will serve the best interests of the United States at this critical juncture in our national space program."

Shuttle flights are planned to begin February 18, 1988, with the launch of Discovery. The first payload will be a NASA Tracking and Data Relay Satellite (TDRS), the second of three such satellites needed to provide a critical communication link in space. (The third TDRS is slated for the fourth Shuttle mission.)

The first science payload, the Hubble Space Telescope (HST), is scheduled for launch on November 17, 1988, aboard Atlantis.

The HST is one of several science payloads that have been waiting in the wings since the Challenger accident. Most science missions are scheduled for the second and third years of operation. In flight order they are ASTRO-1, an ultraviolet telescope, January 19, 1989; the Magellan probe to map the surface of Venus by high-resolution radar, April 25, 1989; the Galileo mission to Jupiter or the Ulysses solar-polar mission or the Mars Observer mission, November 1, 1989; the Gamma-Ray Observatory to investigate gamma-ray sources, January 18, 1990; and Galileo, Ulysses, or the Mars Observer (one of the two that didn't go up in 1989), October 10, 1990.

The first two years of Shuttle flights will attempt to relieve the backlog of national security payloads, including various Department of Defense (DOD) projects relating to the Strategic Defense Initiative and a global navigation satellite. Time has also been allowed between each of the initial flights so that engineers can analyze the performance of the redesigned solid rocket motors. The second flight occurs more than three months after the first; about two months are allotted between each of the following seven flights.

Five flights are planned for 1988, ten for 1989, and eleven for 1990. Four additional flights are scheduled in 1991, and an outline of sixteen additional flights (flight numbers but no specific dates) is given through 1994, including a "planetary opportunity" launch in 1992. The first flight of Challenger's replacement, currently designated OV-105, is scheduled for March 1, 1991.

One of the obvious conflicts in the new manifest is the launch dates for the Galileo, Ulysses, and Mars Observer missions. Because each mission has to be launched at intervals when Earth and Jupiter or Earth and Mars are at specific orbital locations in the solar system, only one mission can be accommodated per launch "window." Currently, Galileo mission planners are banking on the November 1989 launch date; the next planetary launch date is eleven months later in October 1990.

Despite this rescheduling, NASA is still faced with a substantial backlog of payloads, a backlog that was accumulating even before the Challenger accident. The decision not to fly commercial or foreign payloads (except those that have national security or foreign policy implications) has eased the schedule somewhat, but not enough.

To relieve the situation, NASA has designated a number of missions as candidates that can be launched via expendable rockets. Of the science missions, these include the Galileo spacecraft, the Gamma-Ray Observatory, and the Cosmic Background Explorer (which will study the diffuse radiation of the universe), though the latter mission has yet to be given a specific launch date.

A new class of Titan expendable launcher, the Titan 4 — being developed by the Air Force — is expected to be ready for launch in 1988 and will be capable of lofting Shuttle-sized payloads into low-Earth orbit. NASA has considered launching Galileo on a Titan 4, but the military will have to agree to swap one of its Shuttle-compatible payloads with Galileo.

The new manifest is by no means etched in stone. As Fletcher put it, the manifest "must be a dynamic document. It will be reviewed constantly to reflect such factors as the NASA and DOD budgets, NASA's ability to meet our milestones for resuming operations, and customer decisions."

Optical Telescope Proposed for Interferometric Studies

Plans for a two-mirror, optical-infrared telescope — one that would look much like a pair of giant binoculars — are under study by the University of Chicago, the University of Arizona, and Ohio State University. The universities have formally joined to create the telescope, and a fourth partner is expected to join the project soon.

The proposed 11-meter telescope, with two 8-meter mirrors carried side-by-side in the same mounting, would be the first large optical telescope designed for interferometry.

Interferometry is a technique that allows astronomers to see objects in much finer detail than possible with a single-mirror telescope. Interferometric observations are made when the images from two or more telescopes are combined in such a way that the resolution of images is equivalent to that of a much larger telescope. Interferometry has been used in radio telescopes for many years and is just now becoming practical in visible and infrared astronomy.

The telescope would be used to study extremely distant, primitive galaxies and gas clouds in which stars are born. Scientists also plan to use it to search for answers about how stars and their planets form and about how the universe originated and evolved.

The telescope will also take advantage of a new technique called adaptive optics, which provides higher resolution and allows the observation of dimmer and more distant objects by countering the degrading effects of atmospheric turbulence on images.

More than $1 million has already been committed to the telescope's design. If it is completed by 1992 as projected, the instrument is expected to cost about $50 million. It will be built on the summit of Mount Graham, Arizona, pending U.S. Forest Service approval.

Gamma-Ray Bursters Might Be as Distant as Quasars

Are gamma-ray bursters phenomena occurring within our neighborhood of the Galaxy or distant objects at the edge of the observable universe? In a letter published in the September 15, 1986, issue of *Astrophysical Journal Letters*, Bohdan Paczynski of the Princeton University Observatory proposes the latter hypothesis. If proven it would mean that gamma-ray bursters are many orders of magnitude brighter than quasars.

Astronomers have theorized about gamma-ray bursters since these phenomena were discovered in 1967. Numerous models have been proposed to explain them, the most popular involving a neutron star's rapid burning of excess matter drawn copiously from a companion star. The sudden release of energy, predominantly in the form of gamma rays, would be seen as a flash of visible light in the sky. Many events have been sporadically observed, and some may have even been photographed (see "Gamma-Ray Source Pinpointed," AstroNews, June 1986). Still, their brief, unpredictable signals have made research attempts difficult.

Most theorists also think gamma-ray bursters are relatively nearby, between 100 and 1000 parsecs. If they are at cosmological distances, like the quasars, gamma-ray bursters would have to release incredible supernova-like amounts of energy — on the order of 10^{51} ergs within less than a second — to appear as brightly as they do. This would make them, briefly, the brightest objects in the universe.

Paczynski bases his proposal on certain properties of gamma-ray bursters: they are known to have a brightness duration of about one second; their distribution throughout the sky is isotropic (or uniform in all directions); and the number of gamma-ray bursters increases as their brightness decreases (i.e., there are more faint bursters than bright ones).

Paczynski states that there are not enough nearby neutron stars to account for the isotropic distribution of gamma-ray bursters. At greater distances (from outside the Galaxy looking in, as it were), gamma-ray bursters should be found primarily either within the galactic disk or at its

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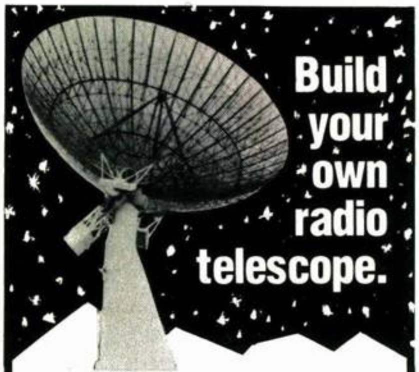

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center, the locations where most known galactic objects are concentrated. However, gamma-ray bursters are seen throughout the sky, not just along the galactic plane or hub. Moreover, the fact that their number increases as their brightness decreases, Paczynski says, implies that they are not evenly distributed throughout space.

According to Paczynski, these conclusions leave two possibilities: either gamma-ray bursters are very local, perhaps within the Oort Cloud at the edge of the solar system, or they lie out near the edge of the observable universe.

Gas Jet Seen Projecting from Seyfert Galaxy

A faint jet of ionized gas has been discovered projecting from the Seyfert galaxy Markarian 315, located in Pegasus. The narrow filament, visible in images obtained by a charge-coupled device, extends 60 kiloparsecs northwest of the galaxy, then bends back at an angle of about 150° and continues to the southeast for 80 kiloparsecs. Unlike the bright blue plasma jets shot out of violently active galaxies such as M-87, the jet projecting from Markarian 315 may be a "tidal tail" of material drawn out of the galaxy by interacting with another galaxy.

The discovery of this jet was made by John W. MacKenty while he was at the Institute for Astronomy at the University of Hawaii. He is now with the Space Telescope Science Institute in Baltimore. Details were published in the September 15, 1986, issue of the *Astrophysical Journal*.

Observations of this and other active galaxies offer a number of clues that support the hypothesis that this jet is the result of a gravitational interaction with another galaxy. According to MacKenty, there is no evidence to show that material is actually shooting out of the galaxy as a result of a violent ejection in the galaxy's core. Instead, the portion of the filament extending 25 kiloparsecs from the galaxy's nucleus is more strongly ionized than the rest of the jet, suggesting that the source of this ionization is the energetic nucleus.

Seyfert galaxies also tend to occur in interacting or disturbed galactic systems. As has been proposed, their active nuclei may be sustained by the tidal material produced by interactions. Radio observations also reveal that star formation, another result of a past interaction, is occurring on a large scale within Markarian 315's disk.

One problem with the interaction hypothesis is that a companion galaxy is not readily apparent in the region. The two nearest galaxies visible on Palomar Observatory Sky Survey plates — an elliptical and a barred spiral — do not appear to be gravitationally disturbed. However, the lifetimes of these two systems are unknown, and redshift values have yet to be obtained for them. This information would show whether or not they are truly within the vicinity of Markarian 315.

Palomar Anti-Light Pollution Campaign Scores Victory

The fight against light pollution in the vicinity of Palomar Observatory continued to make progress in 1986. Following the successful push for restrictions on street lighting in the San Diego County area, new laws have been enacted that now restrict most types of outdoor lighting as well.

The new ordinances, according to Robert Brucato, assistant director of the observatory, are based on four goals. "One, use the minimum amount of outdoor lighting possible. Two, orient and shield the light so it goes downward. Three, if the light is not needed, turn it off. And four, for things like roadways, parking lots, and security lighting, use low-pressure sodium lamps."

San Diego County passed outdoor lighting legislation in January 1985. On June 10, 1986, the city of Vista, twenty miles west of Palomar, passed a similar ordinance. The Vista legislation places restrictions primarily on new outdoor lighting. Shielded, low-pressure sodium lighting fixtures are required for security lighting; shielding and automatic timing devices are required for commercial and industrial lighting. Also, lighting used "to illuminate on-premise signs or for architectural or decorative effects" must be directed toward the ground instead of the sky.

The ordinance requires that new and existing lighting be turned off from 11 p.m. until dawn, with the exception of security lighting and lighting at commercial, recreational, or industrial facilities open after 11 p.m. Luminous tube lighting and Christmas decorations are exempt from the restrictions. *Tom Wilson.*

An 11-Minute Binary?

Astronomers have discovered what may be a binary star with a period of 11 minutes. If proven, this would be the shortest-period binary system known. It would also be the first direct proof of a collision between two stars.

The discovery was announced at the ninth European meeting of the International Astronomical Union held last September at the University of Leicester, England. An article in the September 11, 1986, issue of *Nature* credited William C. Priedhorsky of the Los Alamos National Laboratory, New Mexico, and Luigi Stella and Nicholas E. White of the European X-Ray Observatory Satellite (EXOSAT) Observatory, with the discovery.

The star is a known x-ray burst source (an object that punctuates its steady emission of x-rays with intense bursts of

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x-rays within a period of a few seconds). Designated 4U1820-30, it lies at the core of the 8th-magnitude globular cluster NGC-6624 in Sagittarius. However, the conundrum is that none of the known x-ray bursters exhibit regular pulsations, making this misfit either an exception to the rule, or a new type of object.

Could 4U1820-30 be a rotating neutron star? According to Priedhorsky *et al.*, the increased "spin rate" caused by matter accreting onto the surface of the neutron star would most likely be detectable. But so far no evidence for such a spin-up has been detected. If spin periods are ruled out, says Priedhorsky, then the orbit of a companion star might account for the regular periodicity observed for this object.

If this is a binary star with an 11-minute period, the characteristics of such a system would be unusual to say the least. The two stars would have to be no more than 100,000 kilometers apart and could easily fit between the Earth and Moon. Although the unseen companion must be very small, probably a white dwarf of about 0.07 solar masses, the total mass of the system would have to be roughly one and a half times that of the Sun.

Frank Verbunt of the Max Planck Institute for Astrophysics suggested at the IAU meeting that the binary could have evolved from the gravitational capture of an incipient core of a red giant by a neutron star in the dense stellar regions of the globular cluster. Orbiting inside the red giant's envelope would exert frictional drag on the neutron star, which in turn would cause it to lose angular momentum and spiral toward the core. At the same time the giant's shell would be heated and then ejected, leaving the giant's helium core and the neutron star.

Eventually the additional loss of angular momentum due to gravitational radiation would decrease the stars' distance even more, causing the period to shorten to a few minutes. Once close enough, matter would be pulled off the white dwarf onto the neutron star, until enough matter accumulated to cause it to erupt as a bright x-ray source.

Other suggested explanations to account for the 11-minute period included the precession of the rotational axis of a rapidly rotating neutron star and the existence of a separate x-ray source that happened to lie within EXOSAT's field of view during its observations of 4U1820-30.

Astronomers are hoping to take a closer look at the object sometime after the launch of an x-ray satellite by Japan this February. Investigation of the new binary will be one of its priorities. Since the demise of EXOSAT last April, no new x-ray satellites have been launched, bringing x-ray astronomy observations to a near halt. American or European satellite projects seem unlikely before the mid-1990s.

ASTRONOMY AstroCalendar

January 4-8
169th Meeting of the American Astronomical Society (professional meeting sponsored by Mount Wilson Observatory and Caltech), Pasadena, California. Contact: AAS, 1816 Jefferson Pl. NW, Washington, DC 20036.

January 17
Astronomy Day '87 (exhibits, speakers, observations), Callaway Gardens, Pine Mountain, Georgia. Contact: Dr. Carole Rutland, Patterson Planetarium, 2900 Woodruff Farm Road, Columbus, GA 31907. Phone: (404) 568-1730.

January 29-February 1
3rd Annual Winter Star Party (sponsored by the Southern Cross Astronomical Society), Everglades National Park, Florida. Contact: Tippy D'Auria, 1051 N.W. 145 St., Miami, FL 33168. Phone: (305) 685-6001.

February 4-March 15
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February 12-14
Automatic Photoelectric Telescopes II (Fairborn IAPPP Symposium), Apache Junction, Arizona. Contact: Russell M. Genet, Fairborn Observatory, 1357 N. 91st Pl., Mesa, AZ 85207.

February 21-22
American Workshop on Cometary Astronomy (sponsored by the International Halley Watch), Jet Propulsion Laboratory, Pasadena, California. Contact: Comet Workshop, International Halley Watch, 169-214 Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109.

March 14
Astrophoto VII (symposium on amateur astrophotography, sponsored by Ventura Co. Astronomical Society and Orange Co. Astronomers), Moorpark College, Moorpark, California, at 8 a.m. Contact: VCAS/Astrophoto VII, P.O. Box 982, Simi Valley, CA 93062.

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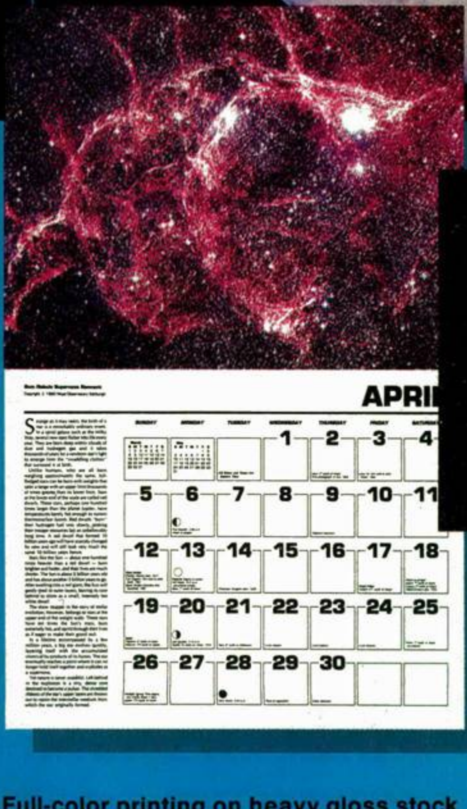

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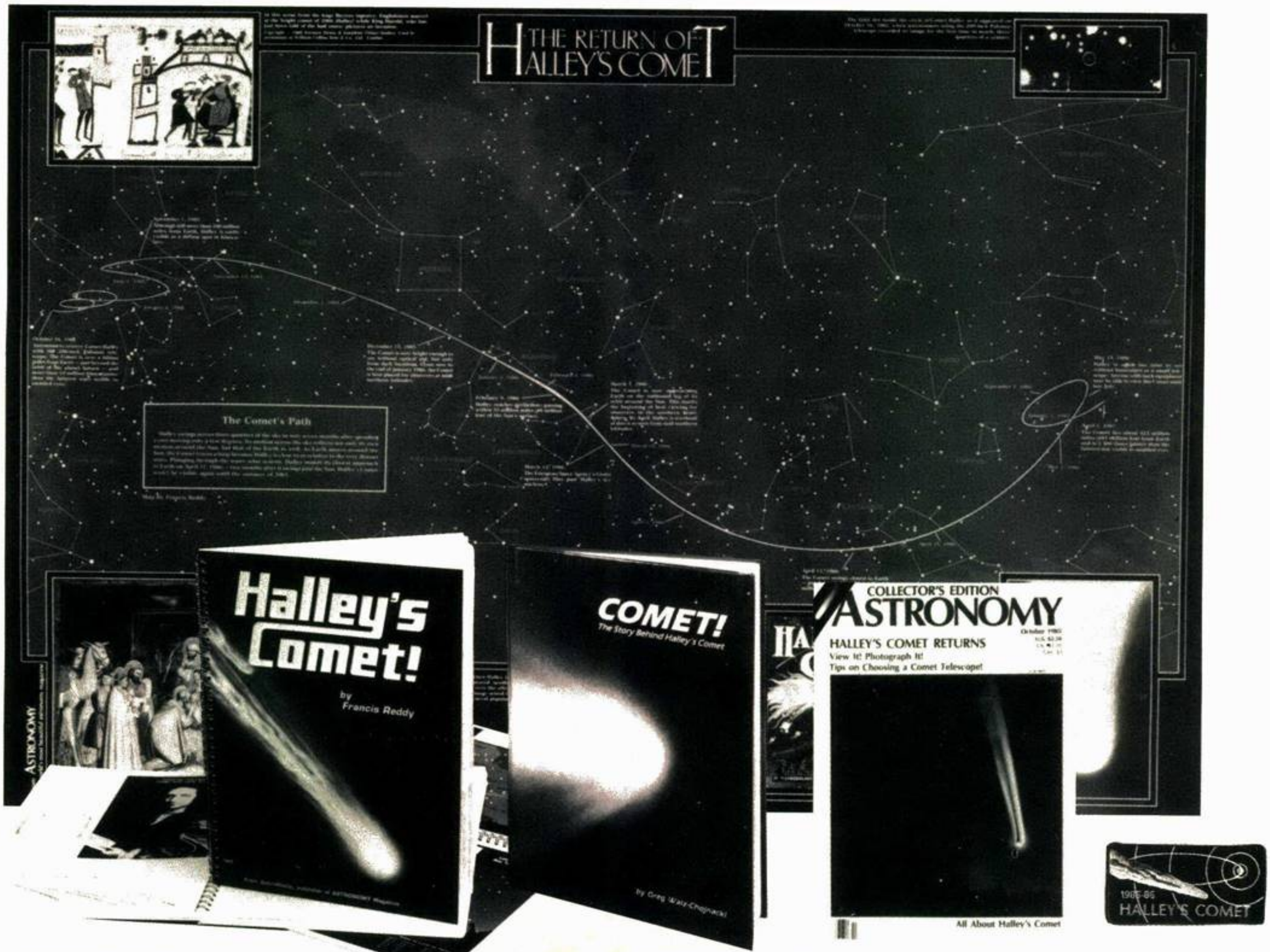
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The Eye's View of Comet Halley

by Charles S. Morris

> *"It is unfortunate that the newspapers and the general public were so greatly disappointed in the comet — unfortunate from the fact that the general impression left by such reports would be exceedingly misleading when comparing the present return with descriptions of its appearance in earlier times. . . . It would have been a gratification to know that everyone who saw this wonderful object saw it with the same spirit of elation and wonder. . .with which the average astronomer regarded it. . . . The great cities that have grown up since 1835, and the smoke and electric lights of today completely robbed the comet of its glory when seen by dwellers in and near the centers of population."*

Instead of referring to the recent passage of Comet Halley through the inner solar system, this description by the great visual observer Edward Emerson Barnard summarizes the comet's 1910 apparition. Despite numerous warnings by astronomers that the 1985/86 return of Comet Halley would be inferior to that of 1910 and, quite possibly, inferior to any return in the previous two thousand years, many onlookers were greatly disappointed that Comet Halley failed to provide a spectacle.

Those who observed carefully enjoyed an entirely different picture of Comet Halley. What they saw was an active, dynamic, and changing comet that offered a variety of insights into the nature of comets.

But why should we be interested in visual observations of this comet, especially nowadays, when so much sophisticated instrumentation, including more than five space probes, was aimed at the comet? Because only visual observations are available for all but one of the previous apparitions, and because visual observations were a significant part of the 1910 apparition. Thus, the visual observations link the apparitions and will help us determine whether or not there have been any significant changes in the comet's behavior. Although it may take years to sort through all the visual observations submitted to the International Halley Watch, *International Comet Quarterly*, and other archives of cometary data, it is possible to get an idea of Comet Halley's general behavior from a preliminary review of visual observations.

Halley Inbound

In January 1985, long before most observers had begun to prepare for Comet Halley, amateur astronomer Stephen O'Meara reported that he had seen Comet Halley visually — the first such observation since before World War I. Peering into the eyepiece of a 24-inch telescope on the summit of Mauna Kea, O'Meara had detected the exceedingly faint light of a comet nearly half-a-billion miles from the Sun. Unlike the other "firsts" to follow, O'Meara's sighting is important because, at 19.6 magnitude, his is the faintest visual observation of a comet ever made, and is by far the faintest visual brightness estimate we have for Comet Halley. His observation, which has sparked heated debate over the ultimate limits of human vision, nonetheless serves to remind us what a powerful sensor the human eye can be.

Not until the end of July, as it emerged from conjunction with the Sun, was Comet Halley again seen visually. Despite predictions that the comet might appear as bright as 12th magnitude, the interloper showed as no more than a 15th-magnitude smudge barely visible to experienced observers using professional-class telescopes. It was not until the Moon had left the sky in August that Comet Halley had brightened sufficiently to be shown as a 14th-magnitude, half-arc-minute, diffuse spot at the limit of large amateur telescopes instead of the "fuzzy star" reported by some hopeful Halley observers.

Halley brightened rapidly during August, reaching magnitude 13.2 at the end of the month. It was anticipated that the comet would be 12th magnitude when the Moon left the sky two weeks later. True to form, Comet Halley did not do the expected. The comet, about magnitude 13.2, looked about the same, prompting many observers to speculate that the comet would not even live up to the most pessimistic predictions of its performance.

It was after this "false start" that Comet Halley went into high gear. In the two-week observing window in September, the comet's brightness increased by a factor of 5 and its size tripled. The diffuse patch began to show a distinct brightening toward its center. Large telescopes revealed a faint stellar condensation, or "false nucleus." They also showed that the coma of Halley began to elongate toward the west — the beginning of a tail.

In October the comet continued the trend started the previous month, brightening one- to two-tenths of a magnitude per day. By the second week in October several observers had glimpsed Halley in large binoculars. Its 4′ coma continued to grow, doubling in size in about a week. During the lunar eclipse on October 28 (in Universal Time, as are all other dates given in this article), the comet was reported at magnitude 8.2.

With the comet rapidly approaching Earth and intrinsically brightening much faster than had been anticipated, the stage was set for an early naked-eye recovery. By November 3, Halley was at magnitude 7.5, one-and-a-half magnitudes brighter than the more conservative projections made by the Smithsonian Astrophysical Observatory's Daniel Green and myself, but close to the prediction made by Joseph Marcus, who publishes a comet newsletter, the *Comet News Service*.

Halley's coma was increasing in brightness by some 0.3 magnitudes per day and had grown to 15′ in binoculars. Just prior to moonrise on the morning of November 8, when the comet was close to the meridian, Stephen Edberg and I glimpsed Halley with the naked eye. The publicity given this sighting was astounding, especially since the sighting lacked scientific importance and many other observers saw the comet within a few nights.

At about this time many of us who had studied the comet's previous apparitions began to wonder if we had totally misjudged Halley's ability to brighten. Perhaps the comet would put on a spectacular show after perihelion. Even if the rate of brightening slowed, as it sometimes does as a comet approaches the Sun, it was difficult to see how Comet Halley could fail to surpass all expectations. On November 27 when the comet had made its first close approach to Earth, 0.62 astronomical units away, it was 5th magnitude, some 20′ in diameter, and had a short tail in binoculars.

However, two things were changing. The change everyone expected was that the comet would begin to move away from the Earth as it swung around the Sun and that some of its intrinsic brightening would be offset by its greater distance. The *unexpected* change was that the comet's rate of intrinsic brightening also slowed — not gradually, but suddenly.

Throughout December hopes dwindled for a spectacular post-perihelion performance. The comet's increasing geocentric distance resulted in almost no change in the comet's apparent brightness. At the beginning of the month Halley appeared as a large, faint, fuzzy ball about a degree in diameter to the naked eye, though it was much smaller in binoculars. The tail remained short — a couple of degrees in length — and rather faint. By the end of the month the angular size of the coma, shining between magnitude 4.0 and 5.0, had shrunk. This was due, in part, to the rapidly increasing distance between Earth and the comet.

As 1986 began, the comet looked like a slightly fuzzy star to the naked eye. It seems unlikely that ancient observers would have even noticed this tail-less "broom star." In binoculars, however, Halley's tail was starting to show signs of improvement. By the second week of the year the tail, although still quite faint, had grown to more than 5° in length and had been spotted with the naked eye. This was the gas tail.

Keen-sighted observers might also have noted the beginnings of Halley's dust tail along the south side of the gas tail. For Comet Halley to be impressive the dust tail would have to be a prominent feature after the comet's closest approach to the Sun. This is because the eye is more sensitive to the wavelengths reflected by dust than to those emitted by fluorescing cometary gas. As it approached perihelion and conjunction with the Sun, the comet began to brighten again, reaching magnitude 3.8 before it was lost in bright evening twilight toward the end of the month.

Halley Outbound

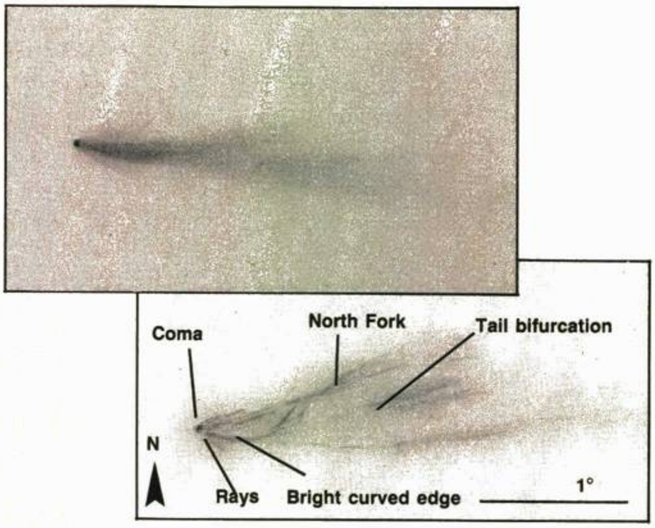
With much anticipation comet observers around the world waited for Comet Halley to emerge from the Sun's rays in the morning sky. Since Halley was now quite far south in the sky, it was first picked up by Southern Hemisphere observers in mid-February. A few days later Northern Hemisphere observers caught sight of the comet. Even in bright moonlight it was apparent that the comet had brightened to between magnitude 3.0 and 2.5 and had a much more obvious tail. As the Moon waned Comet Halley emerged in all its glory — a respectable comet with a gas tail more than 10° long. The dust tail, while brighter and longer than before perihelion, still lacked the spectacular look of a Comet Bennett or West. However, even in mid-March there were signs of things to come. In binoculars the comet appeared parabolic, with its gas tail extending toward the west and the dust tail along the north side of the gas tail bending toward the north. With the naked eye, however, a faint fan-shaped tail of dust could be see emanating in a much wider arc toward the north.

Many observers in high northern latitudes would no doubt disagree with this description. For them the comet was low in the sky and, because of atmospheric extinction, unimpressive. Many observers estimated the comet to be much fainter under such poor conditions than it actually was. In some cases, observers could not even find the comet.

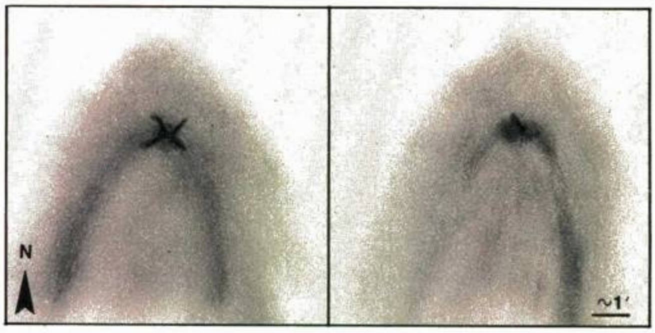
Those who traveled south to get a better view of the comet did not fare as well as they had expected. During the first week and a half of April, a prime time to see the comet, Halley was located in the bright Southern Milky Way. The comet's tail, never very bright, was overwhelmed by the multitude of stars and the brightness of the Milky Way starclouds which were behind it. Although the coma was an obvious naked-eye object of magnitude 2.5, the comet's tail was much shorter than the 30° that had been predicted. How much longer would the tail have been if the comet had appeared in a different part of the sky? We will never know.

To the naked eye, the comet appeared like a wedge in the sky, and the structure of its tail changed from night to night. In binoculars, a faint fuzzy extension on the comet's north side grew more obvious until it had become a sharply defined edge of Comet Halley's dust fan by April 5. The western edge of the fan-shaped tail, bounded by the gas tail, was initially the brightest and longest part of the tail. The eastern edge was defined by

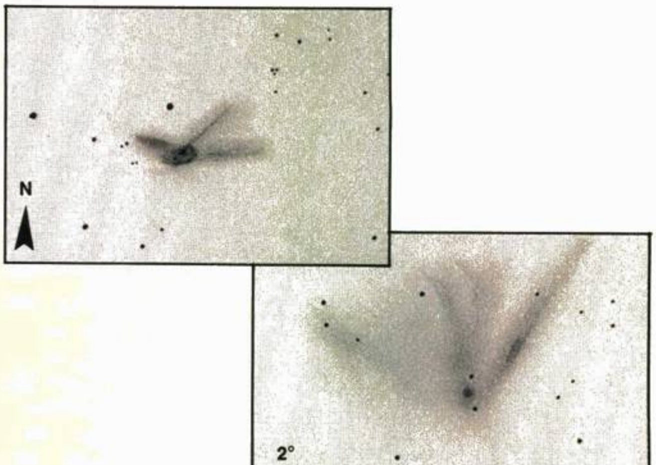
Visual Observations Show the Changing Aspect of Halley



Comet observer Alan Hale sketched the intricate structure in Comet Halley's tail on March 2 at 13 hours Universal Time (March 2.54 UT). The drawing on the left shows how the comet looked; the one on the right highlights unusual tail features. The observation was made using 10x50 binoculars.

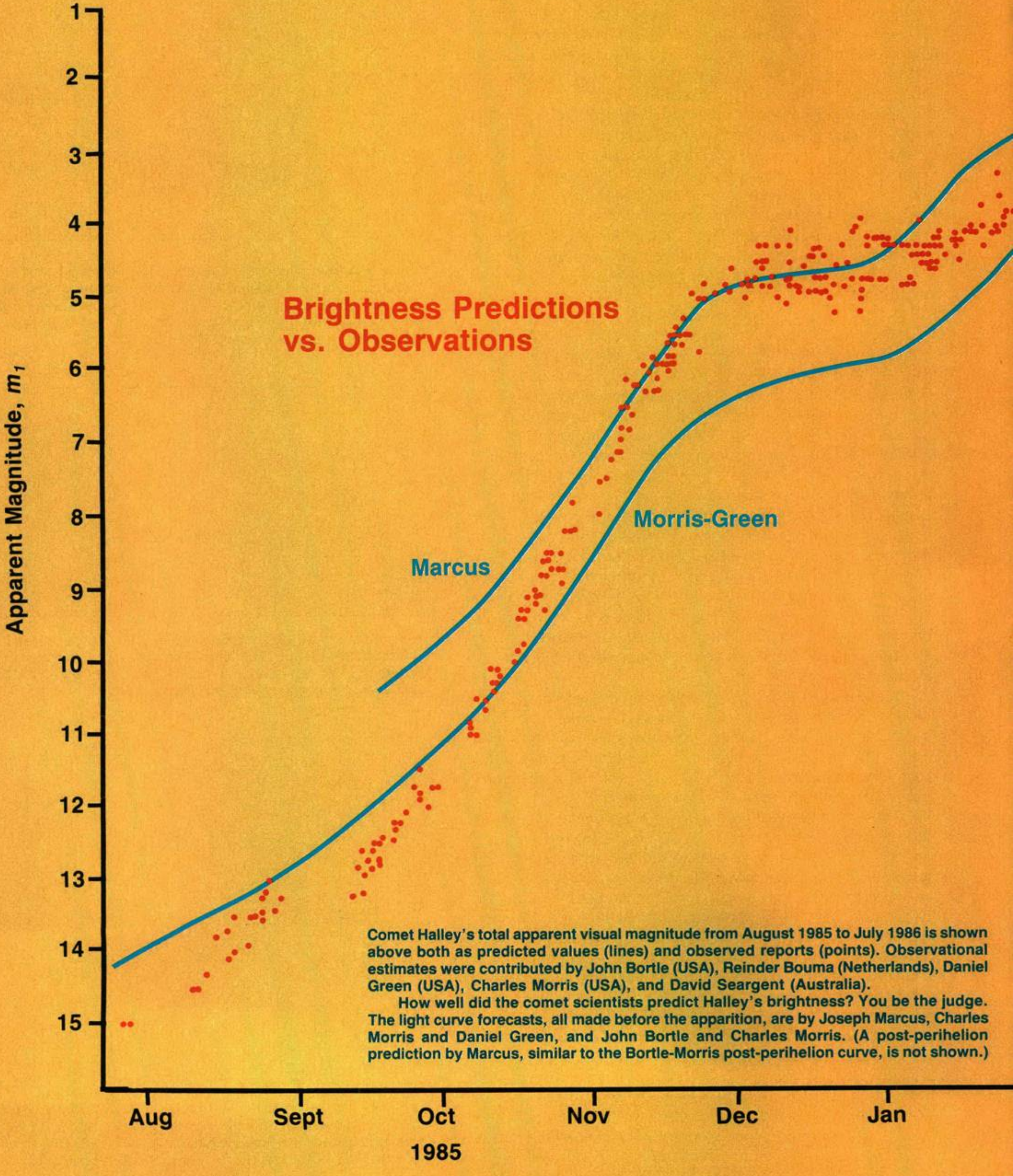


Near-nucleus drawings, made by Australian Terry Lovejoy using an 8-inch reflector at 250x, show night-to-night changes due to jet activity. The left-hand drawing was made March 2.77 UT; the right one shows the comet on March 3.78 UT.



Two sketches record the development of Halley's fan tail in early April. The drawing on the left shows Halley on April 5.58 UT; the other one shows it a week later, on April 12.52. Observations were made by Charles Morris using 10x50 binoculars.

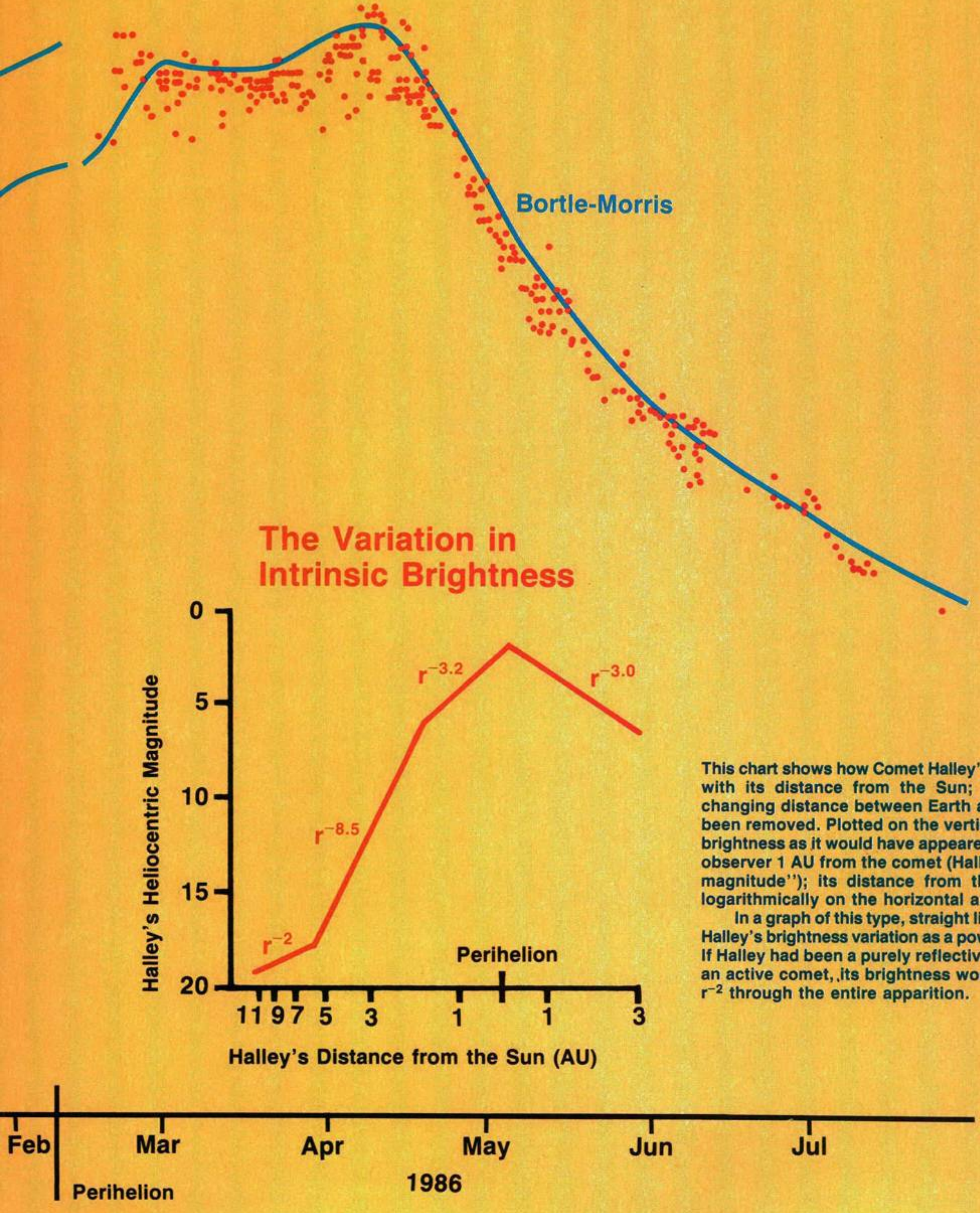
How Bright Was Comet Halley?



Comet Halley's total apparent visual magnitude from August 1985 to July 1986 is shown above both as predicted values (lines) and observed reports (points). Observational estimates were contributed by John Bortle (USA), Reinder Bouma (Netherlands), Daniel Green (USA), Charles Morris (USA), and David Seargent (Australia).

How well did the comet scientists predict Halley's brightness? You be the judge. The light curve forecasts, all made before the apparition, are by Joseph Marcus, Charles Morris and Daniel Green, and John Bortle and Charles Morris. (A post-perihelion prediction by Marcus, similar to the Bortle-Morris post-perihelion curve, is not shown.)

The Variation in Intrinsic Brightness



This chart shows how Comet Halley's brightness varied with its distance from the Sun; the effect of the changing distance between Earth and the comet has been removed. Plotted on the vertical axis is Halley's brightness as it would have appeared to a hypothetical observer 1 AU from the comet (Halley's "heliocentric magnitude"); its distance from the Sun is plotted logarithmically on the horizontal axis.

In a graph of this type, straight line segments show Halley's brightness variation as a power of the distance. If Halley had been a purely reflective body rather than an active comet, its brightness would have varied as r^{-2} through the entire apparition.

The Anatomy of Visual Comet Observing

Marilyn Morgan observes Comet Halley in the predawn March sky using binoculars. Photograph by Charles Morris.

The apparitions of bright comets have been recorded by observers since the dawn of writing. Although the techniques have changed, modern visual observers ask the same basic questions their counterparts did: Where is the comet? How bright is it? What does it look like?

Comet Positions

During Comet Halley's 1910 apparition many important observations were made visually. More recently, however, photographic plates and charge-coupled devices have largely replaced visual observations for measuring position. Only during the first few days following a discovery, before accurate photographic positions become available, are visual estimates of a comet's position still important.

Comet Magnitudes

But the most frequently mentioned property of a comet is its brightness. What does it mean when someone says that a *comet is magnitude 2.5*? It means that the comet's coma or head, if it were stellar, would shine with the brightness of a 2.5-magnitude star. Problems arise because the comas of comets are usually not stellar — they are extended objects.

Because they are extended, comets are harder to see and look less conspicuous than a star of the same brightness. Moreover, the larger the comet, the less obvious it appears, because its light is spread out over some area of the sky. Comet IRAS-Araki-Alcock (1983 VII) is an outstanding example of this effect. Although the magnitude of the coma reached 2.0, many people failed to locate it because it was 3° across.

The apparent coma or total magnitude of a comet, often denoted as m_1, is estimated visually by comparing the comet to stars of known brightness. There are several methods of making this comparison, but all involve putting the stars out of focus so they appear as large as the coma of the comet, comparing the surface brightness of the comparison star or stars to the average surface brightness of the comet, and then estimating the comet's magnitude. The comet's tail is never included in such an estimate.

There are several problems associated with visual magnitude estimates. Perhaps the most significant is that estimates depend on the instrument used. Estimates made with small, low-power telescopes or binoculars, for example, are usually brighter than estimates made with large instruments. To compenstate for this, standard, empirically determined corrections are employed to bring the magnitude estimates made with different instruments into a common system, so the light curve can be studied. Of course the stars used for comparison, the observing location, and the observer's experience in making comet magnitude estimates are also significant factors affecting the accuracy of a comet magnitude estimate.

When a comet has a stellar or near-stellar central condensation, the brightness of this is estimated using standard techniques for estimating the brightness of variable stars. Magnitude estimates obtained this way are called "nuclear magnitudes," and designated m_2. Because m_2 represents the brightness of the nucleus plus that of an undefined amount of the coma surrounding it, estimates of nuclear magnitude are ambiguous and difficult for comet researchers to interpret.

Comet Appearance

Visual observers also report the appearance of comets. One datum is the angular diameter of a comet's coma. The diameter of a comet coma is usually obtained by comparing the size of the comet to pairs of stars with known separation or by measuring the time required for the comet to drift past a crosshair in the eyepiece. Like estimates of magnitude, estimates of coma diameter may vary greatly with the instrument used. For instance, on November 8, 1985, Comet Halley appeared 35′ in diameter to the naked eye, but only half that size when viewed in binoculars.

Comets are best known for their tails. To record the appearance of this feature, an observer sketches the position and length of the tail relative to the surrounding field of stars. Measurements of its length and position angle (the direction the tail is pointing) can be made from a star atlas. For tails more than 10° long, though, it is necessary to use a formula to calculate the tail's length because of the distortion of the atlas.

As with other parameters, the observed tail length often depends on what instrument is used. In all cases the reported tail lengths and coma diameters represent a lower limit to the size of the comet.

Observers with large telescopes often find that observing the inner coma for jets, hoods, or other near nucleus structure is very rewarding. Information gathered this way has been used by Zdenek Sekanina and Fred Whipple to determine rotation periods and the orientation of the nucleus for a number of comets.

Drawings of any cometary feature are recommended. Like a photograph, they provide a record that can be checked long after the observation has been made. To be complete such observations should include field stars of the scale and orientation of the drawing, as well as the date, the time of the observation, the quality of the seeing and the clarity of the sky, the instrument and magnification used, and any other pertinent information.

— Charles S. Morris

the unusually sharp boundary of the dust fan, and this boundary became, at times, more obvious than the gas tail. Between the edges of the tail the faint smear of dust was punctuated, at least on some nights, by a brighter plume of dust.

On the night of April 12, as seen with the naked eye, the gas tail was 13° long and pointed northwest, while 9° of the dust fan edge was prominent toward the east-northeast. The 110° wide fan was bisected by a 9° long plume of dust. On the very next night the gas tail had faded dramatically. By the night of the 14th the central dust plume had become the brightest part of the tail and the fan was beginning to narrow. In telescopes, the gas tail showed an obvious kink partway down the tail. The next night the prominent central dust plume had totally disappeared, and the dust fan took on a uniform appearance. On this night observers first noticed that the tail was growing longer; tail lengths of 10° to 20° were reported.

In moderate-size amateur telescopes Comet Halley was putting on a different kind of show. At high magnification and under good seeing conditions thin lines of material could be seen radiating from the comet's star-like central condensation. At times sectors of the coma near the false nucleus brightened; at other times "hoods" surrounded part of the central condensation. The false nucleus itself sometimes appeared stellar and other times diffuse, and its appearance often varied over the course of about two days — the rotational period of Comet Halley's nucleus. These features resulted from jets of dust emitted by the nucleus — the same kind of jets seen by the Giotto and VeGa spacecraft. The jet activity was not limited to March and April; it began before perihelion and extended into June.

As Earth's shadow swung across the Moon's fully illuminated disk on the night of April 24, observers were treated to an unexpected thrill: the sight of a faint tail stretching more than 25° from Halley's magnitude-3.5 coma. The long tail was still there a few nights later when the Moon was no longer in that part of the sky. It was fainter than the zodiacal light but brighter than the gegenschein, and stretched from the comet's head in Crater, through Corvus, and into Virgo. Halley's long ghostly tail lasted but a few days; as the comet faded, the tail faded with it. The last reported naked-eye sighting of Halley's tail was made May 10, when the comet was about magnitude 5.5.

As Halley faded during May, observers wondered whether this remarkable object, which had been visible to the naked eye for more than half a year, would still be bright enough to detect after the Moon left the sky toward the end of the month. Observing conditions were getting worse as the comet's elevation decreased from night to night.

Despite this, Stephen Edberg of the International Halley Watch and David Levy of the University of Arizona spotted it from an altitude of 7,500 feet on May 25 during the Riverside Telescope Makers' Conference. Several other observers reported possible or definite naked-eye sightings of the comet made as late as May 30. Who saw it last with the naked eye? We will never really know. The comet passed close to a 6th-magnitude star during this time, which made positive identification of the comet almost impossible.

Only die-hard observers were left to follow the comet during its last two months of visibility. In binoculars, a faint tail was visible through much of June. Halley's now-famous fan tail was once again visible, but it was much fainter and only a degree or so long. Comet Halley displayed another tail — pointing sunward — in May and part of June. It was glimpsed by only the most experienced observers and photographed with professional telescopes. The comet was not supposed to have a sunward tail at this time, which left another mystery for comet researchers to solve.

Also during this period, Halley's once star-like false nucleus disappeared, although it did reappear briefly on June 9 when the comet emitted a puff of dust from the nucleus — an event called a nuclear outburst. These events usually start with a bright star-like point of light in the coma. As the dust expands away from the nucleus, the false nucleus looks like an expanding disk. It grows larger and more diffuse each day, and finally fades away entirely.

The last reported Northern Hemisphere observation of the famous comet prior to solar conjunction was made by comet observer Alan Hale from New Mexico on July 13, when the comet had faded to 9th magnitude. Southern Hemisphere honors go to Richard Fleet in Zimbabwe, who detected the comet with a 14-inch reflector nearly a month later.

What We Learned about Comet Halley's Behavior

For many years it has been known that Comet Halley is an intrinsically bright comet. It is about ten times brighter than the average long period comet and perhaps one hundred times brighter than the typical short-period comet. However, Halley's brightness behavior had been a controversial subject for several years preceding this apparition. The chart on page 90 compares the observed visual light curve with some of the predictions. Although no one correctly predicted the comet's brightness before perihelion, the post-perihelion projections were in reasonably close agreement with the observations. The light curve also indicates that there were no major flares or fadings in brightness — Comet Halley was relatively well-behaved.

To learn more about the way Comet Halley's *intrinsic* brightness changed as the comet approached and receded from the Sun, we must remove the effects of the changing distance between Comet Halley and Earth. We then see the comet's intrinsic or heliocentric brightness as a function of the comet's distance from the Sun, expressed in astronomical units (AU). This has been done in the chart on page 91 for the entire apparition — from October 1982 through July 1986.

From 11 AU to about 6 AU (October 1982 to November 1984) the comet's average brightness varied as the inverse square (r^{-2}) of the comet's heliocentric distance. That is, when the distance to the Sun decreased by a factor of 2, the comet would increase in brightness by a factor of 4. This is exactly what would be expected for a simple reflecting body. However, superimposed on this average trend were fluctuations on a magnitude or more. Although the rotation of the nucleus may have contributed to these variations, it is possible that other processes were at work. Astronomers have yet to determine what was happening, but it appears that even at such large distances from the Sun, Comet Halley may not have been completely dormant.

At about 6 AU from the Sun Comet Halley began to brighten at a rate greater than expected from reflection only. This was its "turn on" point. For the next year Comet Halley brightened at a rate of $r^{-8.5}$. This is equivalent to saying the comet increases in brightness 362 times when the distance to the Sun is divided by 2.

At about 1.75 AU in November 1985 the comet "put the brakes on." Its rate of brightening dropped to $r^{-3.2}$, equivalent to an increase by a factor of 9 when the comet's distance from the Sun halves.

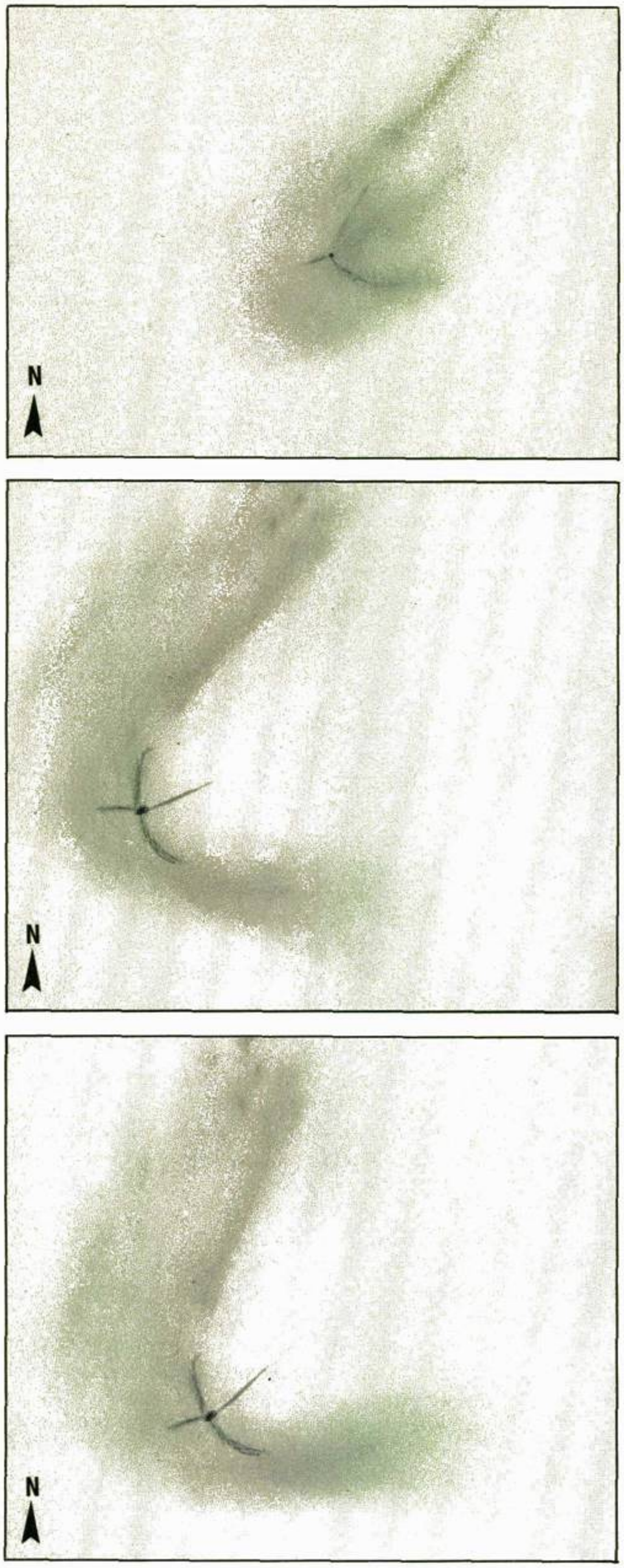
Comet Halley reached its greatest intrinsic brightness about two weeks after perihelion, as predicted by comet observer John Bortle and myself. After that it faded at a rate of $r^{-3.0}$, which is equivalent to an eight-fold dimming when the comet's distance from the Sun doubles.

How does this compare to previous apparitions? In 1910 the comet was followed in from 3 AU and out to 5 AU from the Sun. Although different pre-perihelion predictions based on the 1910 data did not agree, we can see in retrospect that the comet performed about the same in 1985/86 as it had in previous apparitions, both on approach to the Sun and on leaving it. In addition, we now have a better insight into what observers were seeing in the previous apparitions of Halley and have learned better how to interpret ancient records of comet sightings.

The Tail of Comet Halley

Quite possibly the greatest surprise of Comet Halley's appa-

Drawings Depict Near-Nucleus Detail



This series of drawings by observer David Levy show nightly variations in Comet Halley's jets. The first shows the comet on March 24.52 UT and was made through light cirrus clouds. The second was made March 25.52 UT and shows an elongated central condensation and strong jets. The third drawing, made March 26.53 UT, shows a jet pointing down the tail. Levy used a 16-inch reflector to make these drawings.

rition was the appearance of the tail. How could the predictions for a 30°- or 40°-long tail in early April be in error by a factor of 5? Why did the tail become long in late April? Are comets *really* that unpredictable?

The answer to the question has several elements. The first was the comet's location in the sky. For about the first week and a half of April Comet Halley was superimposed on the bright Southern Milky Way. This background limited the amount of tail that was visible. However, this alone cannot account for the reduced tail length.

The biggest factor was Comet Halley's dust fan itself. In early April we were looking at a thin sheet of dust face-on rather than side-on. Although our line of sight made, at most, a 28° angle with the fan and the orbital plane of the comet, this provided the worst viewing angle during the post-perihelion period. Because our line of sight passed through the thin dimension of the dust tail it appeared much dimmer.

In addition, the edge of the fan, which in space made about a 90° angle with the gas tail, was pointed away from us in early April. Our view of it was thus foreshortened. By the end of the month our line of sight made an angle of only 6° to the comet's orbital plane, so we were looking through a greater length of dust. Since the edge of the fan was approximately perpendicular to our line of sight at the time, we could see its full length. As Earth's and Halley's relative orbital positions changed during April, our ability to see a long dust tail improved greatly.

Still another factor in the story of Comet Halley's tail was the history of its dust emission. The character of the dust tail is determined by particles emitted days, weeks, or even months before, because the dust takes a relatively long time to move away from the nucleus. As a result, it is not uncommon for bright comets to have their longest physical tail lengths two or three months after perihelion. Thus, part of the observed lengthening of Halley's tail may have been real.

Although the dust fan had been predicted by Zdenek Sekanina of the Jet Propulsion Laboratory for this current apparition, the physical tail lengths derived from observations at previous apparitions always assumed that the tail was pointed directly away from the Sun. Clearly this was not the case for Halley's dust tail this time since the gas tail *was* pointed radially away from the Sun, but the dust tail did not coincide with it. Lengths quoted for Comet Halley's dust tail at previous apparitions are in the range of 0.8 to 1.0 AU. However, if one assumes favorable geometric conditions, as at previous apparitions, and a dust fan, the length of Halley's dust fan turns out to be about half as long as we previously thought it was, or about 0.5 AU. The gas tail reached a maximum length of about 0.4 AU, some 37 million miles, in March and April.

A final note concerning Halley's tail. Most of us, myself included, assumed that a 30° tail would be bright along much of its length, making it a fine sight in the sky. Anyone who saw how dim the tail was at the end of April understands what a poor assumption this was. The tail was present, but it was by no means bright.

Visual observations from the 1985/86 apparition of Comet Halley are an integral part of the data that will be studied for many years to come. However, it is sad to note that this was, in all likelihood, the last time that visual observers will contribute significantly to the study of this fascinating object. Just as the technology of 1986 is vastly superior to that of 1910, the technology of 2062 will give us far more powerful ways to study Halley, possibly including astronomer astronauts who sample material from the surface of Halley's nucleus.

Charles S. Morris works at the Jet Propulsion Laboratory, has degrees in astrophysics and atmospheric science, and is associate editor of the International Comet Quarterly. *In the past eighteen years Morris has observed more than eighty comets; he observed Comet Halley on 161 nights.*

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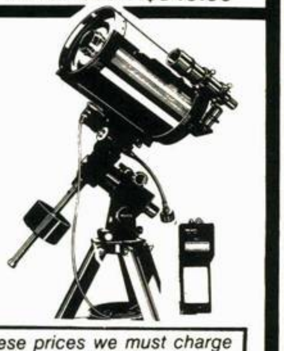

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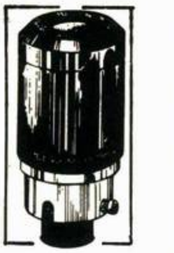

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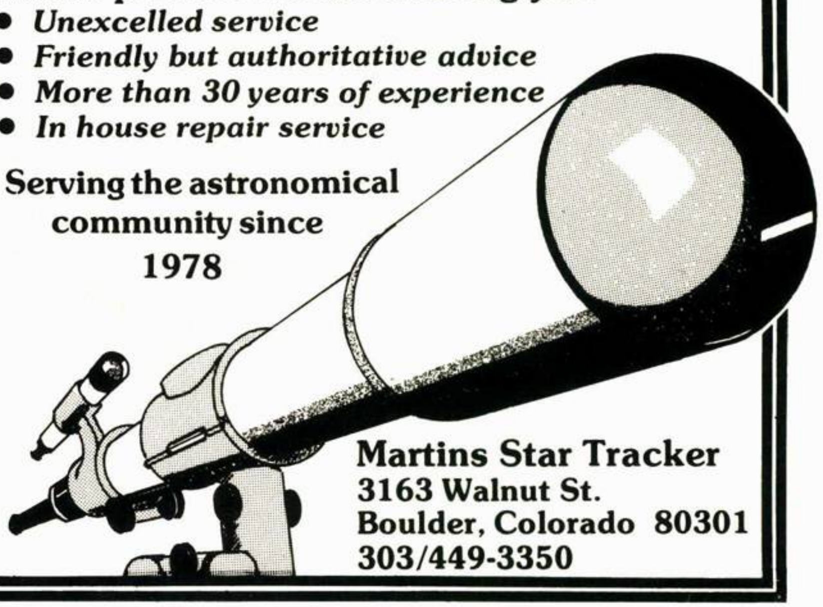

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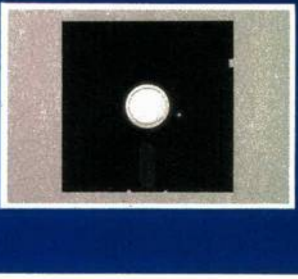

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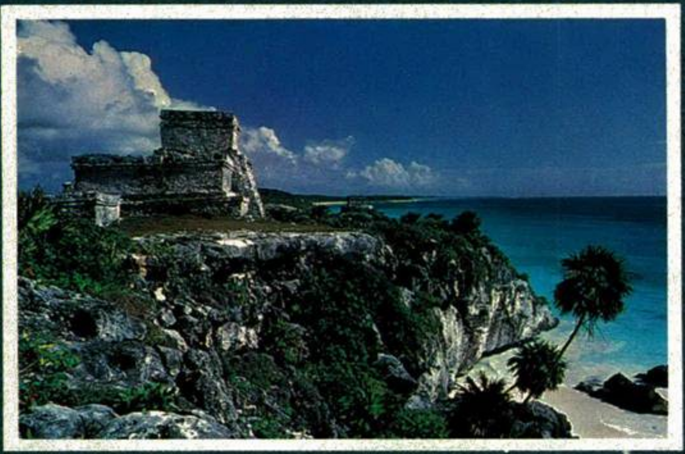

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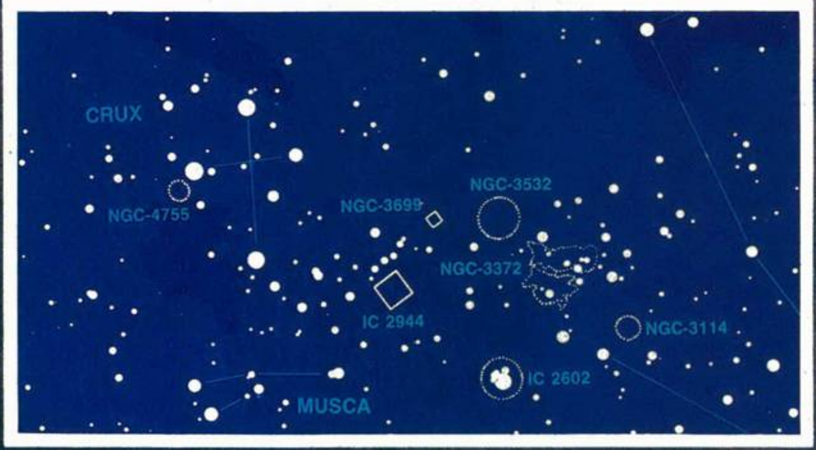

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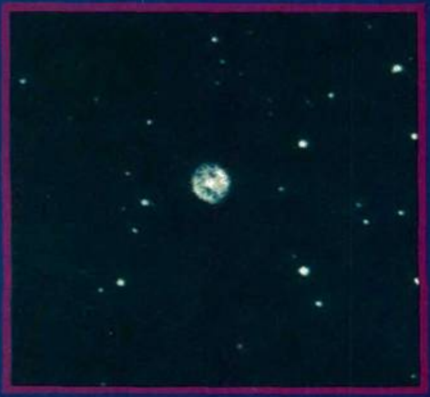
Above: NGC-2403 is one of the brightest galaxies in the northern sky. Photo by Jack Newton.

Left: Open cluster NGC-1502 contains forty-five stars in an 8' area and shines at 6th magnitude. Photo by Lee C. Coombs.

Below: NGC-1501 is a faint planetary nebula visible as a hazy smudge in medium-size telescopes. Photo by Lee C. Coombs.



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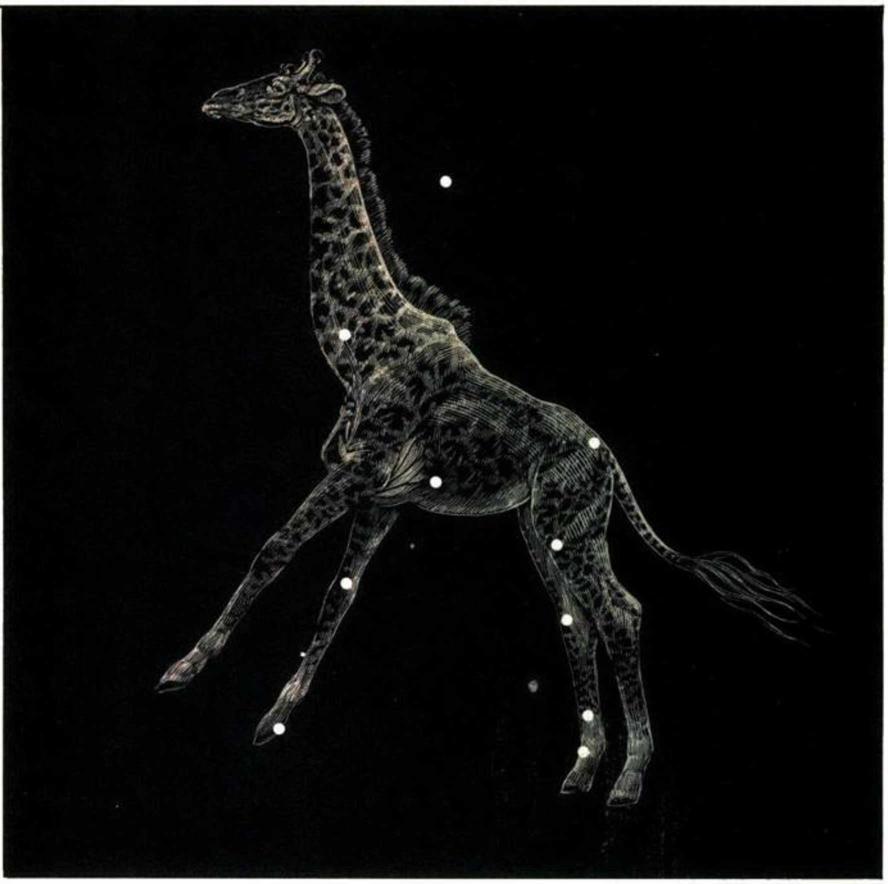


Lying between the rich Milky Way clusters and nebulae of Cassiopeia and the myriad spiral and elliptical galaxies of Ursa Major is the large, inconspicuous constellation **Camelopardalis** the Giraffe. This spindly constellation is far enough away from the galactic equator that it contains plentiful galaxies — including one of the finest spirals in the northern sky — yet it also offers two planetary nebulae and an unusually rich star cluster.

Placed near two 6th-magnitude stars in the southeastern corner of Camelopardalis is the magnitude 8.4 galaxy **NGC-2403**. This magnificent spiral lies only 3.5 megaparsecs away and is a member of the same group of galaxies that includes M-81 and M-82 in Ursa Major.

Because it is relatively near and appears more or less face-on to our line of sight, NGC-2403 presents intricate detail in its spiral arms. The structure of this galaxy resembles that of M-33 in Triangulum, the "Pinwheel Galaxy." Both show loose, mottled patches of bright and dark nebulosity in their arms and bright, small nuclei. Astrophotographers have discovered that recording this detail on film with long exposures and long focal length systems is rather easy. Seeing this detail in either galaxy, however, requires a large backyard telescope and a dark, transparent night.

From suburban or rural locations NGC-2403 is visible in large finder scopes as a nebulous spot of milky light. Viewed with a 4-inch telescope, the galaxy appears as an oval fuzz with a bright core. An 8-inch instrument reveals faint mottling in the galaxy's arms, and the galaxy appears as a bright oval nebulosity surrounded by a dim haze speckled with bright and dark regions visible only with averted vision. Backyard telescopes in the 16-inch class, especially when used with a Deep-Sky filter, show the patchy distribution of light in the galaxy's arms with relative ease. In any telescope the visual appearance of NGC-2403 is highlighted by its location against a rich, starry foreground.

NGC-2403 was the first galaxy outside the Local Group in which Cepheid variable stars were spotted — twenty-seven in all by 1960. About one hundred emission nebulae are known to habitate NGC-2403's graceful spiral arms. The largest of these nebulae — spanning 275 parsecs — are some of the fuzzy knots visible in large backyard instruments.

Nearly 4 hours of right ascension west and a little north of NGC-2403 lies the large, round barred spiral **IC 342**. Once thought to be a member of the Local Group of galaxies, this spiral lies at a distance of about 3 megaparsecs, which makes it too distant to be considered a Local Group galaxy.

IC 342 is so heavily obscured by the thick Milky Way in front of it that the spiral went undiscovered by astronomers until relatively recently. It was discovered by W. F. Denning in 1890, who reported it to J. L. E. Dreyer for inclusion in the first *Index Catalogue* in 1895. Denning and Dreyer considered IC 342 a fuzzy galactic nebula; it wasn't until 1934 that two Mount Wilson astronomers, Edwin Hubble and Milton Humason, discovered IC 342's spiral structure and identified it as a galaxy.

A large telescope is necessary for a satisfactory view of IC 342. The galaxy spans 17.8′ by 17.4′ and brightly glows at magnitude 9.1 in blue light (its visual magnitude is brighter yet). But its light is so spread out that IC 342 has a very low surface brightness and individual little pieces of it appear dim. A 4-inch scope reveals a fuzzy spot of nebulosity, the galaxy's nucleus, surrounded by a bright, colorful starfield. An 8-inch telescope shows IC 342 as a moderately bright circular fuzz surrounded by a very faint 10′-diameter haze that appears strongest using averted vision. A 17.5-inch scope shows this galaxy as a bright, compact nucleus centered in a large halo of nebulosity with patchy striations suggesting spiral arms. The entire glow is peppered with tiny stars.

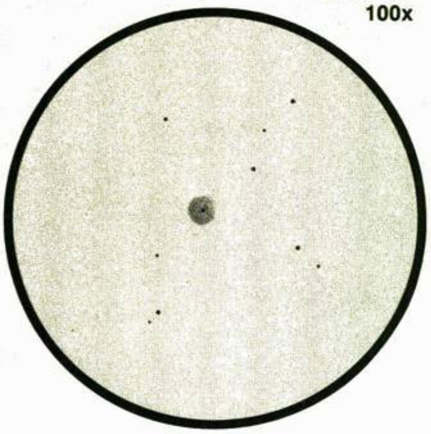
Midway between NGC-2403 and IC 342 lies the little-observed spiral **NGC-1961**. This galaxy is a type-Sb peculiar system, shining at 11th magnitude and measuring 4.3′ by 3.0′ across. In backyard telescopes it appears as a roundish glow some 2′ across with a bright nucleus and faint fuzzy halo of nebulosity.

Several Camelopardalis galaxies lie at high enough declinations that they are circumpolar from the mid-northern latitudes. **NGC-2366** lies at declination +69° and is a curious irregular galaxy. Though its total magnitude is 11, which makes it technically bright enough to see in a

For information on naked-eye sky viewing, including planets, constellations, and mythology, see **Eye on the Sky**.

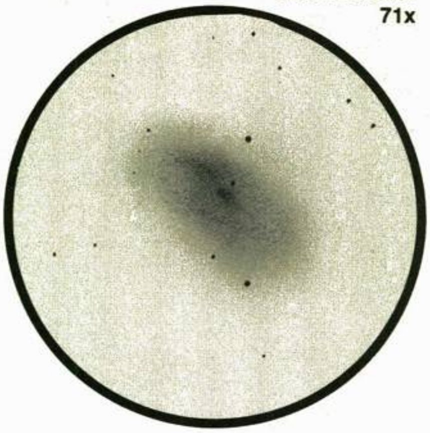
NGC-1501

8-inch
f/10 SCT
100x



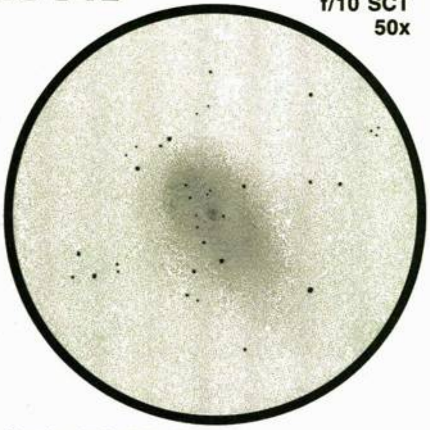
NGC-2403

17.5-inch
f/4.5 reflector
71x



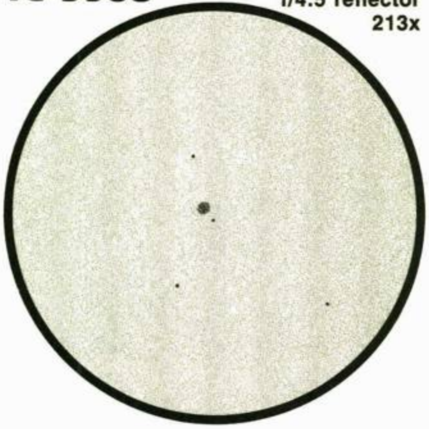
IC 342

8-inch
f/10 SCT
50x



IC 3568

17.5-inch
f/4.5 reflector
213x



Sketches by David J. Eicher

3-inch scope, the galaxy has a rather low surface brightness. Its magnitude and overall dimensions of 7.6′ by 3.5′ make it visible as a misty patch of nebulosity in a 5-inch telescope.

NGC-2523 is a beautiful barred spiral lying at declination +73°. Although it glows at only 12th magnitude and covers a scant 3′ by 2′ of sky, this object is attractive in 10-inch and larger scopes, which show it as a small oval fuzz with a faint circular nucleus. A 16-inch telescope at high power clearly shows the galaxy's bar encased in a ring of gray-green nebulosity. If you observe with a large telescope, don't pass this object on your next night out.

Three galaxies lie at +78° declination, separated by 3 hours of right ascension. **NGC-2146** is a magnitude 10.5 barred spiral wedged between two scattered groups of bright stars in the central part of Camelopardalis. It appears as an oval smear of greenish nebulosity, measuring 6.0′ by 3.8′ in full angular extent. Large scopes reveal its bright nucleus and a mottled faint haze representing the galaxy's spiral arms. Lying only 2° apart are the galaxies **NGC-2655** and **NGC-2715** in the constellation's northeastern corner. NGC-2655 is a 10th-magnitude barred spiral measuring 5.5′ by 4.4′; NGC-2715 is an 11th-magnitude spiral measuring 5.0′ by 1.4′. Each is visible as a nebulous smudge when viewed with a 3-inch scope.

NGC-2336 is the northernmost of Camelopardalis' bright galaxies, lying at +80° declination just south of a triangle composed of two 6th-magnitude stars and one 7th-magnitude star. This object is a fine sight in backyard scopes. A spiral glowing at magnitude 10.5 and measuring 6.9′ by 4.0′, NGC-2336 appears as a bright oval nebulosity surrounding a concentrated, nearly stellar core.

The bright galactic objects in Camelopardalis consist of one open cluster and two planetary nebulae. **NGC-1502** holds forty-five stars in an area measuring 8′ across, giving it a rich, crowded appearance even in finder scopes. With a total magnitude of 5.7, NGC-1502 is technically a naked-eye object under a pitch black sky, but it is small enough to make identifying it a difficult task. The best views of this cluster come with 6- to 12-inch scopes at low power, which show a group of stars widely ranging in magnitude and color.

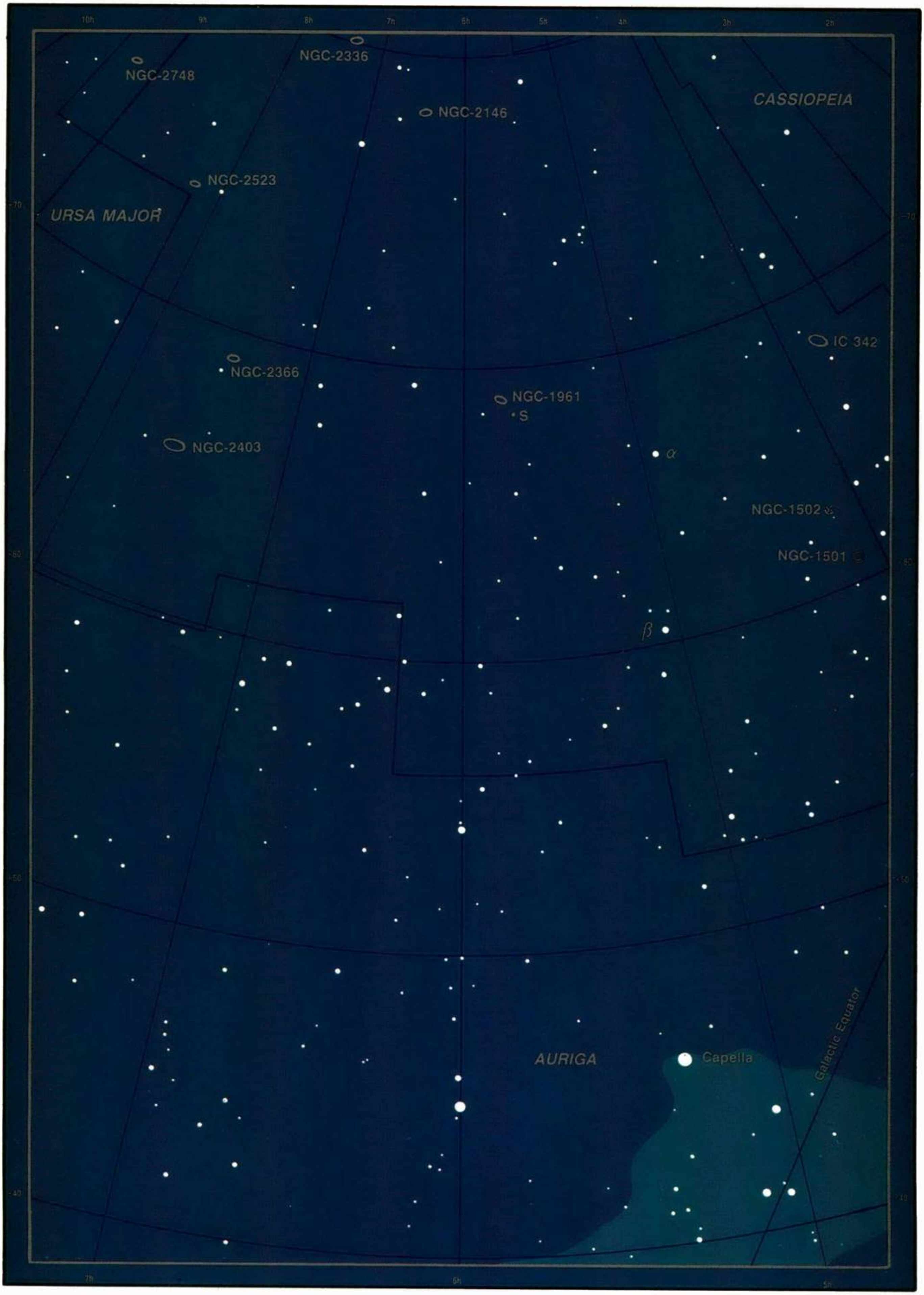
Camelopardalis' two planetaries offer a striking contrast to each other. **NGC-1501** is a typical planetary nebula: a small, bright, smoke ring with a faint central star. **IC 3568** is a faint, exceedingly small object that will test the limits of your equipment, your visual acuity, and the sky's steadiness.

Object	M#	Type	R.A. (2000)	Dec.	Mag.	Size/Sep./Per.	H
IC 342		§B	3h 46.8m	+68°06′	9.1_B	17.8′x 17.4′	S(B)c
NGC-1501		■	4h 07.0m	+60°55′	13.3_P	52″	
NGC-1502		⊙	4h 07.7m	+62°20′	5.7	8′	
S		SRV	5h 41.0m	+68°48′	7.7↔11.6	327.2d	
NGC-1961		§	5h 42.1m	+69°23′	11.1	4.3′x 3.0′	Sb pec
NGC-2146		§B	6h 18.7m	+78°21′	10.5	6.0′x 3.8′	SBb$^-$ pec
NGC-2336		§	7h 27.1m	+80°11′	10.5	6.9′x 4.0′	Sb
NGC-2366		#	7h 28.9m	+69°13′	10.9	7.6′x 3.5′	Ir$^+$
NGC-2403		§	7h 36.9m	+65°36′	8.4	17.8′x 11.0′	Sc
NGC-2523		§B	8h 15.0m	+73°35′	12.0	3.0′x 2.0′	SBb$^-$
NGC-2655		§B	8h 55.6m	+78°13′	10.1	5.1′x 4.4′	S(B)a
NGC-2715		§	9h 08.1m	+78°05′	11.4	5.0′x 1.9′	Sc
NGC-2748		§	9h 13.7m	+76°29′	11.7	3.1′x 1.3′	Sc
IC 3568		■	12h 32.9m	+82°33′	11.6_P	6″	

SRV	*Semiregular Variable Star*
⊙	*Open Star Cluster*
■	*Planetary Nebula*
§	*Spiral Galaxy*
§B	*Barred Spiral Galaxy*
#	*Irregular Galaxy*

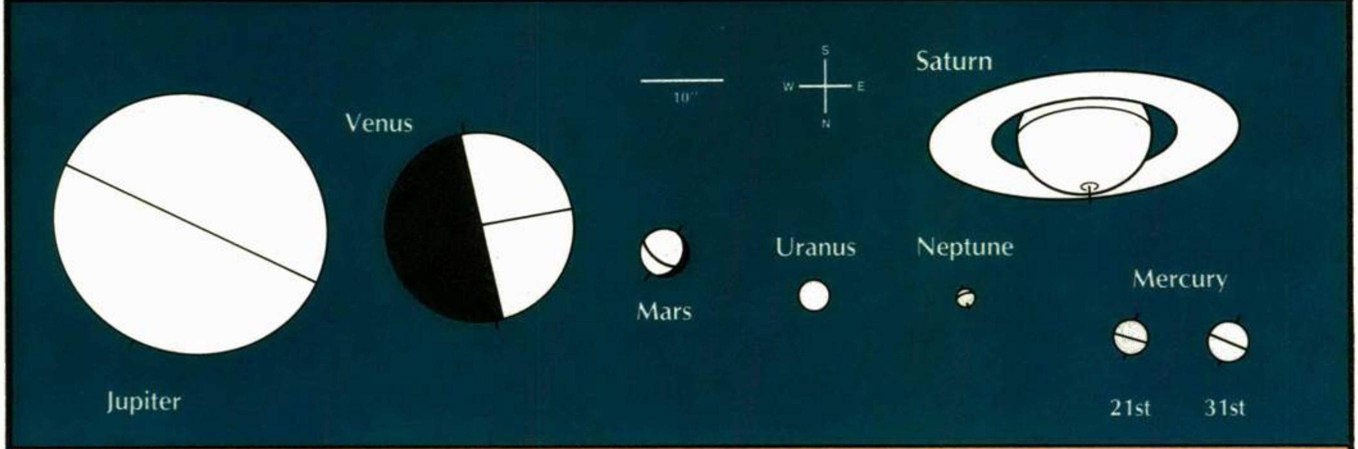
H = Hubble type for galaxies

Subscript "P" denotes photographic magnitude; subscript "B" denotes blue magnitude.

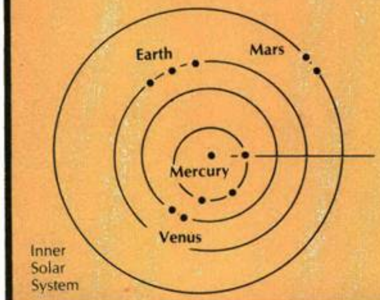

10h
9h
8h
7h
6h
5h
4h
3h
2h
NGC-2748
NGC-2336
NGC-2146
CASSIOPEIA
NGC-2523
URSA MAJOR
70
IC 342
NGC-2366
NGC-1961
S
NGC-2403
α
NGC-1502
NGC-1501
60
β
50
AURIGA
Capella
Galactic Equator
40
7h
6h
5h

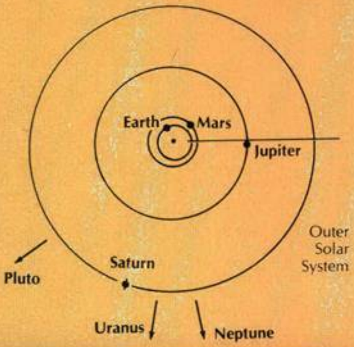
Planetary Data

January 1987


Venus
10″
S
W
E
N
Saturn
Mars
Uranus
Neptune
Mercury
Jupiter
21st
31st

				Angular	%	Distance (AU) from:		Longitude:			
		Date	Mag.	Size	Illum.	Earth	Sun	Heliocentric	Ecliptic	R.A. (2000.0)	Dec.
Sun		1	−26.8	32.6′	—	0.983	—	—	280°01.6′	18h 44.4m	−23°03.1′
		15	−26.8	32.6′	—	0.984	—	—	294°17.6′	19h 45.5m	−21°13.8′
		31	−26.8	32.5′	—	0.985	—	—	310°34.2′	20h 52.8m	−17°32.6′
Mercury	☿	1	−0.8	4.7″	98%	1.427	0.467	258°38.7′	273°23.2′	18h 14.8m	−24°33.9′
		15	−1.2	4.7″	100%	1.418	0.438	299°03.4′	295°55.8′	19h 53.3m	−22°58.2′
		31	−1.1	5.4″	90%	1.242	0.354	0°33.7′	323°17.0′	21h 44.6m	−15°08.9′
Venus	♀	1	−4.6	29.8″	42%	0.560	0.718	134°04.1′	234°24.8′	15h 31.3m	−15°16.7′
		15	−4.5	25.1″	50%	0.666	0.719	156°49.3′	247°37.2′	16h 25.8m	−18°01.2′
		31	−4.3	21.2″	57%	0.788	0.720	182°46.4′	264°34.5′	17h 36.7m	−20°21.2′
Mars	♂	10	0.7	6.6″	88%	1.420	1.454	41°03.0′	1°13.6′	0h 04.9m	0°13.9′
		20	0.8	6.2″	89%	1.502	1.466	46°44.0′	8°12.8′	0h 30.3m	3°10.6′
Jupiter	♃	15	−2.2	36.0″	99%	5.450	4.961	359°20.6′	350°06.2′	23h 25.4m	−4°59.7′
Saturn	♄	15	0.5	15.3″	100%	10.780	10.017	253°28.1′	257°04.3′	17h 04.6m	−21°20.0′
Uranus	⛢	15	5.7	3.5″	100%	20.033	19.186	262°56.5′	264°31.0′	17h 36.4m	−23°26.8′
Neptune	♆	15	8.0	2.2″	100%	31.172	30.239	275°38.3′	276°21.9′	18h 27.6m	−22°16.8′
Pluto	♇	15	13.7	0.1″	100%	29.935	29.699	217°50.5′	219°50.5′	14h 50.3m	0°39.4′

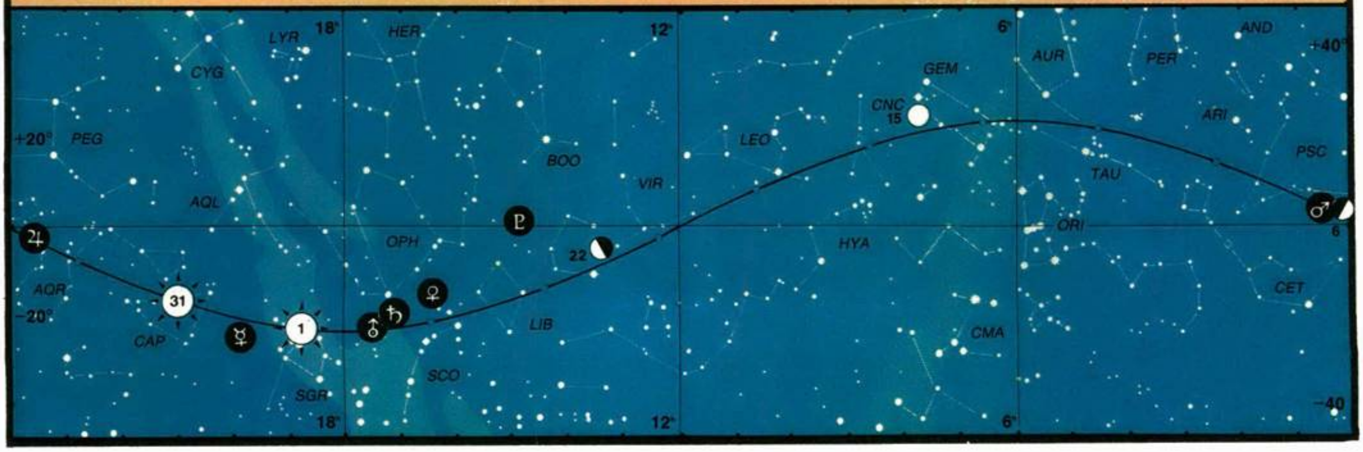

Earth
Mars
Mercury
Venus
Inner Solar System


Earth
Mars
Jupiter
Pluto
Saturn
Uranus
Neptune
Outer Solar System

Moon Data

First Quarter . . . . January 6 at 22h34m
Full Moon . . . . January 15 at 2h30m
Last Quarter . . . . January 22 at 22h45m
New Moon . . . . January 29 at 13h44m
First Quarter . . . . February 5 at 16h21m
Full Moon . . . . February 13 at 20h58m

Apogee: Jan. 13 at 5h00m . . . . . 406,401 km
Perigee: Jan. 28 at 11h12m . . . . 358,894 km


18h
12h
6h
+40°
+20°
−20°
−40
LYR
HER
CYG
PEG
AQL
BOO
VIR
LEO
CNC
15
GEM
AUR
PER
AND
ARI
PSC
TAU
ORI
HYA
OPH
22
LIB
SCO
SGR
CAP
AQR
31
1
CMA
CET
6

Mercury

Although it passes from the morning to the evening sky on January 12, Mercury won't become visible after sunset until very late in the month. On the 31st, it will be only 3° high 45 minutes after sunset. Views of it will be better in February.

Venus

Venus reaches greatest western elongation from the Sun (47°) on January 15, at which time it will be about 25° high in the southeastern sky a few minutes before sunrise. Because Venus is at magnitude −4.5 with a disk 25″ across, it's easy to locate and observe. Use medium to high magnifications (as high as atmospheric seeing allows) and continue your viewing well into twilight to reduce the glaring contrast between the bright planet and the sky around it.

On the 24th, Venus passes less than 2° north of Saturn. The large separation means that you'll need to use binoculars or a good finder scope to squeeze them into one field of view.

Mars

Despite its high elevation in the evening sky, Mars won't look like much in your eyepiece because its disk is only 6.5″ across. Seeing even the largest markings on its surface calls for high magnifications with a telescope of at least 12 inches' aperture and a night with very steady seeing. In a small scope you'll simply see an amber dot of light.

Minor Planets

1 Ceres (magnitude 8.5) is moving southeastward in Ophiuchus. Its positions:

1st: 16h 16m 21s, −17° 22.7′
10th: 16h 31m 03s, −18° 07.9′
20th: 16h 46m 59s, −18° 51.4′
30th: 17h 02m 23s, −19° 28.2′

Ceres rises around 4 a.m. local time on the 15th.

2 Pallas (9.4) is moving eastward in Serpens Caput. On the 11th it passes about a degree south of the globular cluster M-5. Pallas' positions:

1st: 15h 02m 52s, 0° 07.7′
10th: 15h 16m 30s, 0° 46.8′
20th: 15h 30m 45s, 1° 45.8′
30th: 15h 43m 53s, 3° 01.9′

Pallas rises about 1:30 a.m. local time at mid-month.

3 Juno is in conjunction with the Sun on January 3 and is out of sight all month.

4 Vesta (8.0) is moving eastward in north-central Cetus. Its positions:

1st: 0h 44m 28s, −3° 10.0′
10th: 0h 52m 45s, −1° 48.0′
20th: 1h 03m 14s, −0° 12.6′
30th: 1h 14m 51s, 1° 56.0′

Vesta sets around 11 p.m. local time on the 15th.

To locate a minor planet, plot its dated positions (given for 0h UT) lightly in pencil on a good star map (*Sky Atlas 2000.0*, for example) and sketch a smooth curve linking the points. Then observe the starfield at low magnification and photograph or plot by hand what you see. Check the field a night or two later; the "star" that moved is it. (All minor planet coordinates are for the epoch 2000.0.)

Jupiter

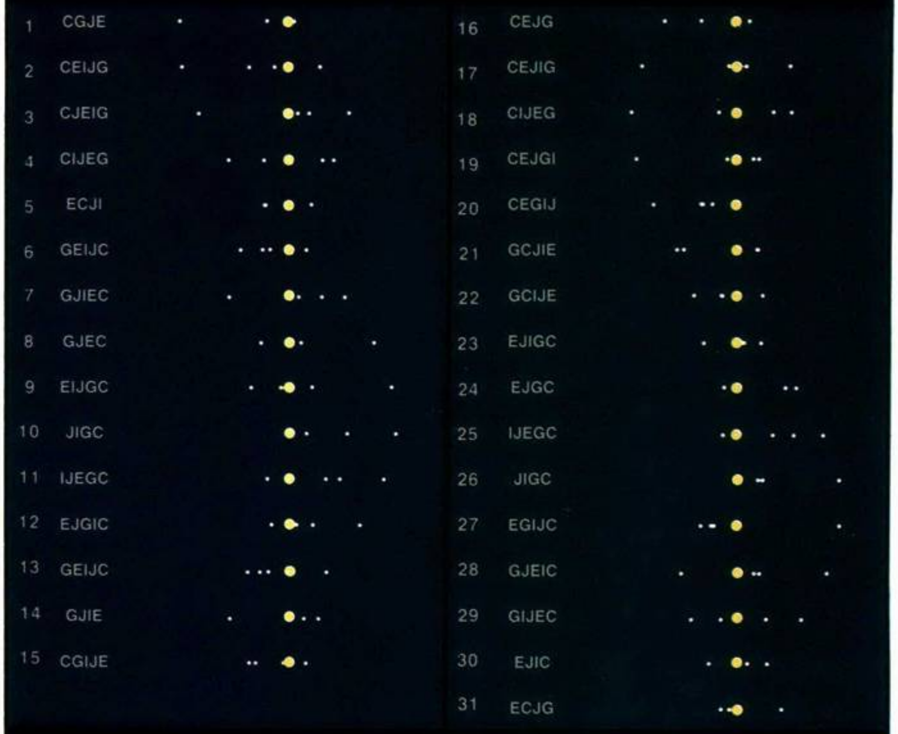
Having been overtaken by Mars last month, Jupiter is now the lower of the two in the evening sky. Despite this, Jupiter is

Elongations of Mercury & Venus — 1987

	Date	Altitude	Azimuth	Type & Extent of Elongation
Mercury	Feb. 12	9°	255°	East (evening sky), 18°
	Mar. 26	2°	105°	West (morning sky), 28°
	June 7	11°	293°	East (evening sky), 24°
	July 25	7°	69°	West (morning sky), 20°
	Oct. 4	1°	248°	East (evening sky), 26°
	Nov. 13	10°	111°	West (morning sky), 19°
Venus	Jan. 15	24°	145°	West (morning sky), 47°

Altitudes and azimuths are given for 45 minutes after sunset (eastern elongations) or 45 minutes before sunrise (western elongations) as seen by an observer at 40° north latitude. In other latitudes the figures will vary slightly. North = azimuth 0° or 360°, east = 90°, south = 180°, and west = 270°.

Satellites of Jupiter 2h00m UT

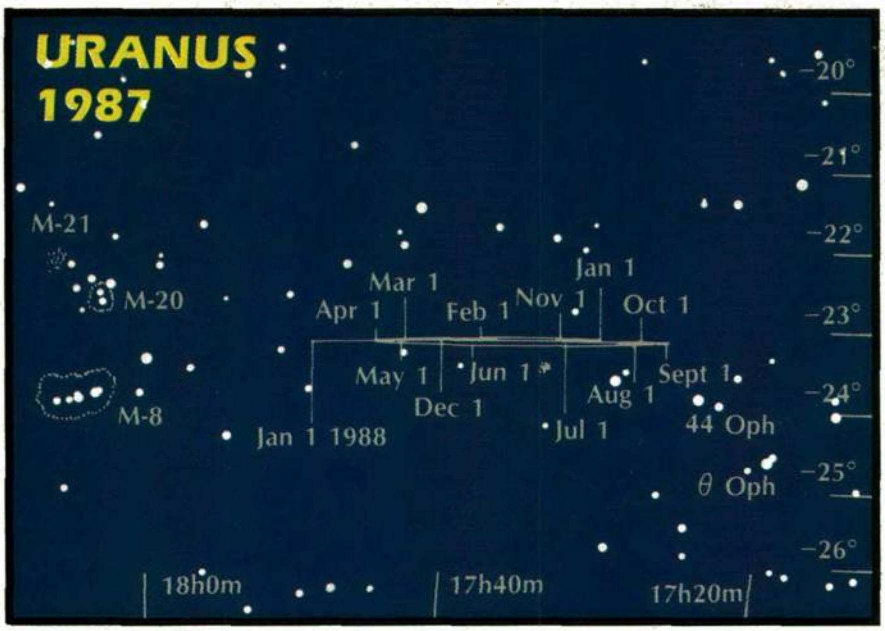


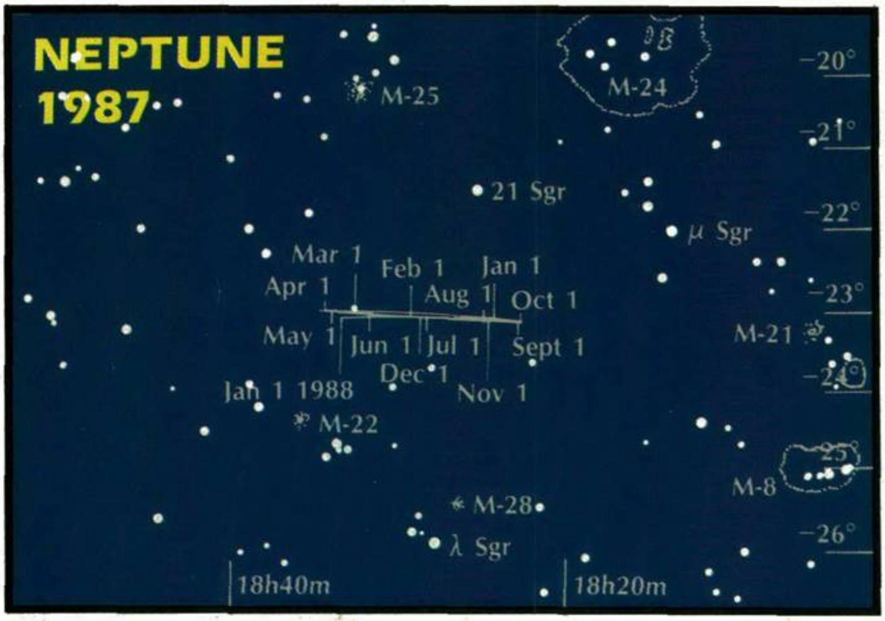
Jupiter = J, Io = I, Europa = E, Ganymede = G, Callisto = C
(South is at top, matching the view in a telescope)

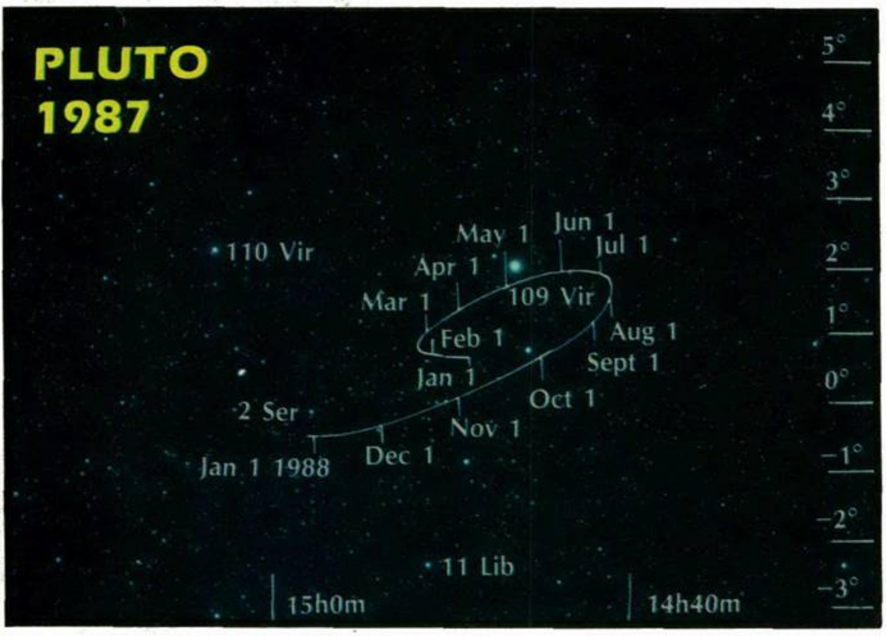
Universal Time

Astronomers the world over use an unambiguous system of time reckoning — Universal Time (UT) — based on a 24-hour clock. Times in "The Backyard Astronomer" are UT unless otherwise noted. To convert UT into your local standard time, subtract the following number of hours for each time zone: EST, 5; CST, 6; MST, 7; PST, 8; Alaska, 9; Hawaii, 10.

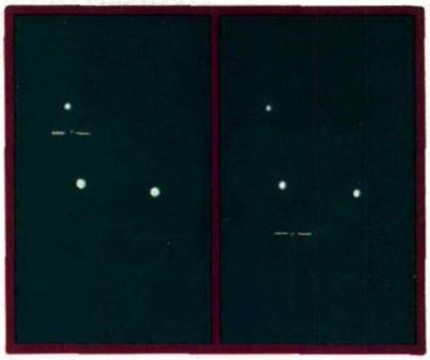
For example, if an event is to happen at 3h00m UT on December 2, then EST for the event is 10 p.m., December 1. Likewise, 13h00m UT on January 5 becomes 5 a.m. PST January 5.


URANUS
1987
M-21
M-20
M-8
Mar 1
Apr 1
Feb 1
Nov 1
Jan 1
Oct 1
May 1
Jun 1
Dec 1
Aug 1
Sept 1
Jul 1
Jan 1 1988
44 Oph
θ Oph
-20°
-21°
-22°
-23°
-24°
-25°
-26°
18h0m
17h40m
17h20m


NEPTUNE
1987
M-25
M-24
21 Sgr
μ Sgr
Mar 1
Feb 1
Jan 1
Apr 1
Aug 1
Oct 1
May 1
Jun 1
Jul 1
Sept 1
Dec 1
Nov 1
Jan 1 1988
M-22
M-21
M-8
M-28
λ Sgr
-20°
-21°
-22°
-23°
-24°
-25°
-26°
18h40m
18h20m


PLUTO
1987
5°
4°
3°
2°
1°
0°
-1°
-2°
-3°
110 Vir
May 1
Jun 1
Jul 1
Apr 1
109 Vir
Mar 1
Feb 1
Aug 1
Sept 1
Jan 1
Oct 1
2 Ser
Nov 1
Dec 1
Jan 1 1988
11 Lib
15h0m
14h40m

Lick Observatory photo



Left: These finder charts show the positions of Uranus, Neptune, and Pluto during 1987. With them you will be able to spot Uranus and Neptune in binoculars or small telescopes. Pluto, however, will require an 8-inch or larger telescope. Charts by David J. Eicher.

Above: Two views of Pluto reveal a 14th-magnitude, slowly-moving "star" that will require careful searching to positively identify. Photographs by Martin C. Germano.

Opposite page: Exquisite photographs of Jupiter and Mars on August 8, 1986, net Californian Mark Coco this month's $100 "Best Astrophoto" prize. Coco used a 16-inch reflector, Ektachrome 200 (for Mars) and Fujichrome 1600D films, and a 1-second exposure for each photo. They are reproduced at the same image scale.

far brighter (magnitude −2.2) than Mars and offers much more to the telescopic observer. Jupiter's disk measures 36″ across the equator, and over the poles the diameter is 34″. This disparity makes the disk appear distinctly oval. Use medium to high powers to spot its cloud belts — and don't just take a hurried look and move on to something else. Take time and give your eye a chance to really *see* what's there.

Saturn

Saturn has emerged from conjunction with the Sun and can be spotted low in the southeast during morning twilight. The planet is still rather low, though, and the chances of getting good telescopic views of it are fairly slim, thanks to poor seeing near the horizon.

Nevertheless you'll still be able to see the rings, if not in much detail. They spread 35″ across (by coincidence, about the same apparent size as Jupiter) and are tipped 26° toward our line of sight. We are looking onto their northern side.

Uranus

Though technically visible in the morning sky, Uranus is too low to be found in the twilight.

Neptune

Farther east than Uranus, Neptune is even more difficult to locate. Wait a month or two to look for both these planets. This will give them time to rise earlier so that their surrounding starfields can be identified more easily.

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26mm	$89
32mm	$115
40mm	$115
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